Report No. 79-2

Fuel

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Demonstration of MARSH TURBO THRUSH to Deliver Pesticides to Coniferous Forests

DECEMBER 1978

Methods Application Group
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Forest Service, USDA
Davis, California

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Reprinted February 1981

Cover photo - MARSH TURBO THRUSH
spraying Idaho forest, 1978.
Photo by W.M. Ciesla.

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DEMONSTRATION OF THE MARSH TURBO THRUSH TO DELIVER PESTICIDES TO CONIFEROUS FORESTS
Phase 2 - Forest Spraying

John W. Barry, George P. Markin, Jerry A.E. Knopf, John Wong[1]

ABSTRACT

A demonstration was conducted near McCall, Idaho, during July-August 1978 to evaluate suitability of the Marsh Turbo Thrush aircraft to deliver pesticides to coniferous forests. A Bell 206-B Jet Ranger helicopter was used as a basis for comparing performance of the Turbo Thrush. Dyed No. 2 diesel fuel was applied to six 500-acre blocks by each aircraft, and the recovery of spray droplets on Kromekote® sampling cards were compared. Spray deposit recoveries showed comparable performance between both aircraft. It is concluded that the Marsh Turbo Thrush is capable of applying pesticides to forests in mountainous terrain.

INTRODUCTION

Helicopters have become the primary vehicle used by the USDA Forest Service (FS) to apply insecticides for control of forest defoliators in the western United States since the 1960's. Previously, fixed-wing aircraft, particularly World War II models, were used for this purpose (Taynton 1967). Relatively inexpensive to operate, these aircraft generally produced acceptable levels of mortality when applying DDT[2] to suppress forest defoliators. Results, however, were often disappointing when these same aircraft were used to apply shorter lived insecticides such as Zectran® (Dewey et al. 1972, McGregor and Dewey 1968). Seeking improved methods, it appeared that maneuverability of the helicopter might make it suitable for application of insecticides close to the forest canopy over complex forest terrain of the western U.S.. Subsequent projects by USDA-FS (Dewey et al. 1974) demonstrated the effectiveness in terms of insect control with the less persistent pesticides when using helicopters maneuvering close to the canopy.

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2 Dichlorodiphenyltrichloroethane.

In recent years cost of aerial application of pesticides to forests has risen dramatically. This fact, coupled with increasing demand and competition for helicopters, has led to renewed interest in using fixed-wing agricultural aircraft (Ekblad et al. 1979).

Piston-powered agricultural aircraft such as the Piper Pawnee, Cessna Ag Wagon, and Grumman Ag-cat have been used on a limited scale to spray forests in the eastern United States. The FS attempted to use small contract agricultural-type aircraft in Washington during 1976; however, the aircraft could not perform effectively (Anonymous 1977). Disadvantages of this class of aircraft have been low payload and performance at high altitudes.

The Marsh Turbo Thrush is the Rockwell Thrush Commander agricultural spray aircraft converted to jet prop. Marsh Aviation of Mesa, Arizona, performs the conversion and markets the aircraft (Figs. 1 and 2).

Figure 1. Marsh Turbo Thrush. Note 400-gallon hopper forward of cockpit. Turbo Thrush test, Idaho 1978.

Figure 2. Turbo Thrush applying dyed fuel oil spray to block. Turbo Thrush test, Idaho 1978.

Phase 1 of this project covered characterization of a chemical and a biological insecticide spray from the Turbo Thrush over flat terrain (Barry et al. 1978). Phase 2, covered by this report, is demonstration of performance in a forest environment.

OBJECTIVE

The Phase 2 objective was to demonstrate the suitability of the Marsh Turbo Thrush aircraft to deliver pesticides to coniferous forests in mountainous terrain. Two tasks were included: to observe flight performance of the Turbo Thrush, and to compare spray deposition pattern of the Turbo Thrush relative to a spray helicopter. Consistent with these tasks it was important to conduct the demonstration in terrain typical of the type sprayed for coniferous forest defoliators and to maintain an operational setting and procedure to the maximum extent practical.

METHODS

The work plan and test design for this project specified a helicopter capable of 90 mph forward speeds while spraying, as atomization is dependent in part upon the shear at the nozzle tip, which is a function of aircraft's forward speed. At 90 mph there is sufficient shear for atomization of the spray. The design of this demonstration was based in part upon both aircraft producing a comparable spray droplet size spectrum.

We were unsuccessful in locating a helicopter capable of flying 90 mph. We were able to locate a Bell Jet Ranger (Fig. 3), capable of spray speeds of about 70 mph. Faced with the option of conducting the demonstration without a helicopter for comparison, we used the Jet Ranger.

Test site was located in Valley County on the periphery of Little Valley (T15N, R4E Boise Meridian), approximately 20 miles south-southeast of McCall, Idaho, and seven miles northeast of Cascade, Idaho (Figs. 4 and 5)[3]. The spray blocks were located in mountainous terrain with forest type and infested by western spruce budworm (*Choristoneura occidentalis* (Free.)). Lands are owned predominately by Boise Cascade Corporation. A small portion of the spray area was located on lands administered by the Boise National Forest and Idaho Departartment of Lands.

Six spray blocks, consisting of three pairs, were established. Each block was 500 acres in size (Fig. 6). Criteria for pairing the blocks included similar character of forest cover, such as stand density, species, and canopy height; similar topography, elevation, and exposure; and avoidance of spray drift from block to block and pair to pair.

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3 Descriptive detail of each spray block is provided in the Appendix.

Figure 3. Bell 206B Jet Ranger helicopter with spray system. Turbo Thrush test, Idaho 1978.

Spray Material

The tank mix consisted of No. 2 diesel fuel and 2% by volume of liquid Automate Red B dye, mixed at the rate of two gallons of dye for each 98 gallons of fuel oil. This mixture was applied at one-half gallon per acre by each aircraft.

Aircraft Operations and Equipment

Air operations involved the following aircraft and missions (Table 1):

One Bell 206B Jet Ranger owned by Cascade Helicopters, Cashmere, Washington. This was the primary spray helicopter equipped with Simplex spray system - external tank and booms (Fig. 3).

Figure 4. Location of spray blocks relative to geographical sites and communities. Turbo Thrush test, Idaho 1978.

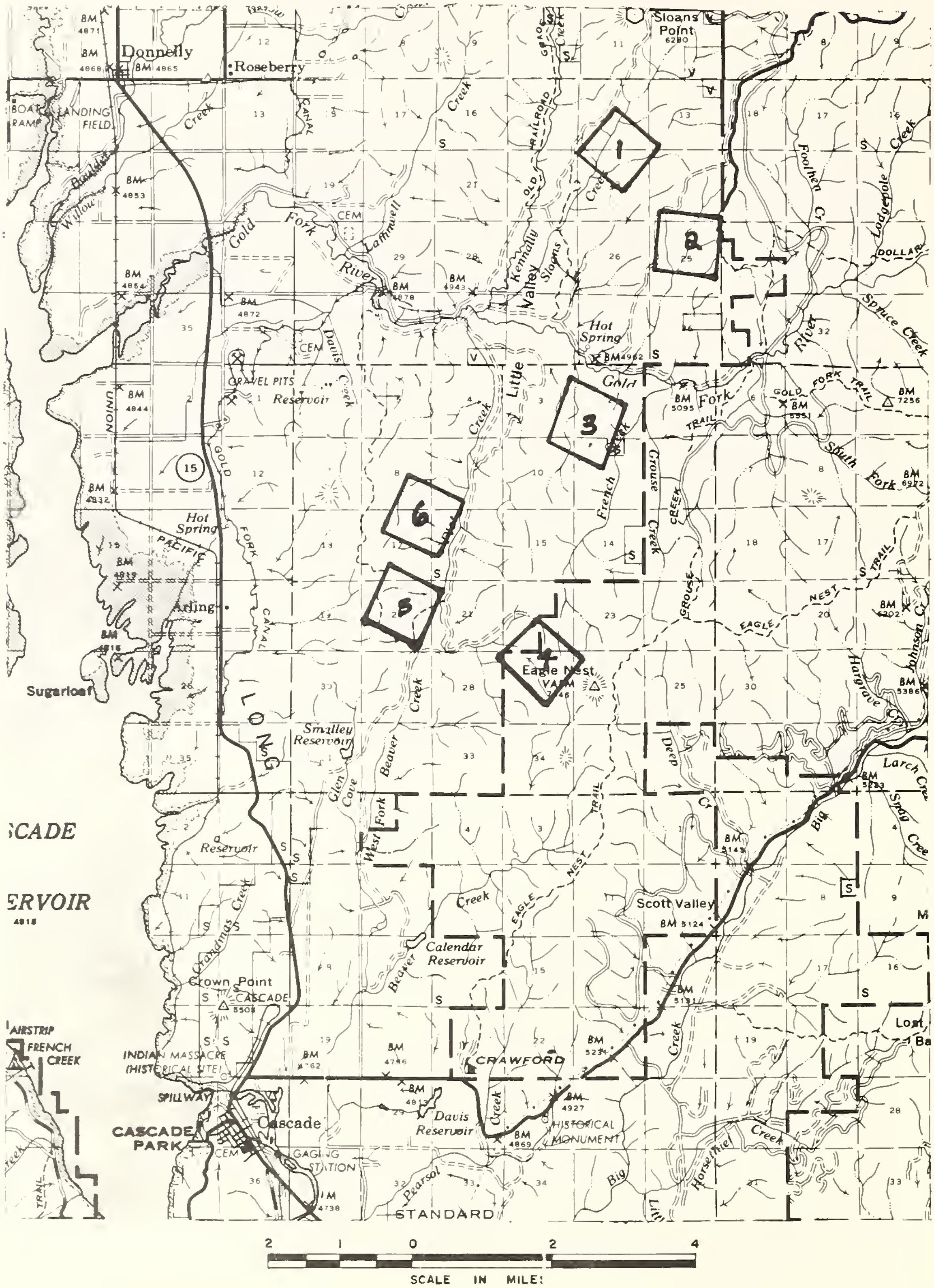
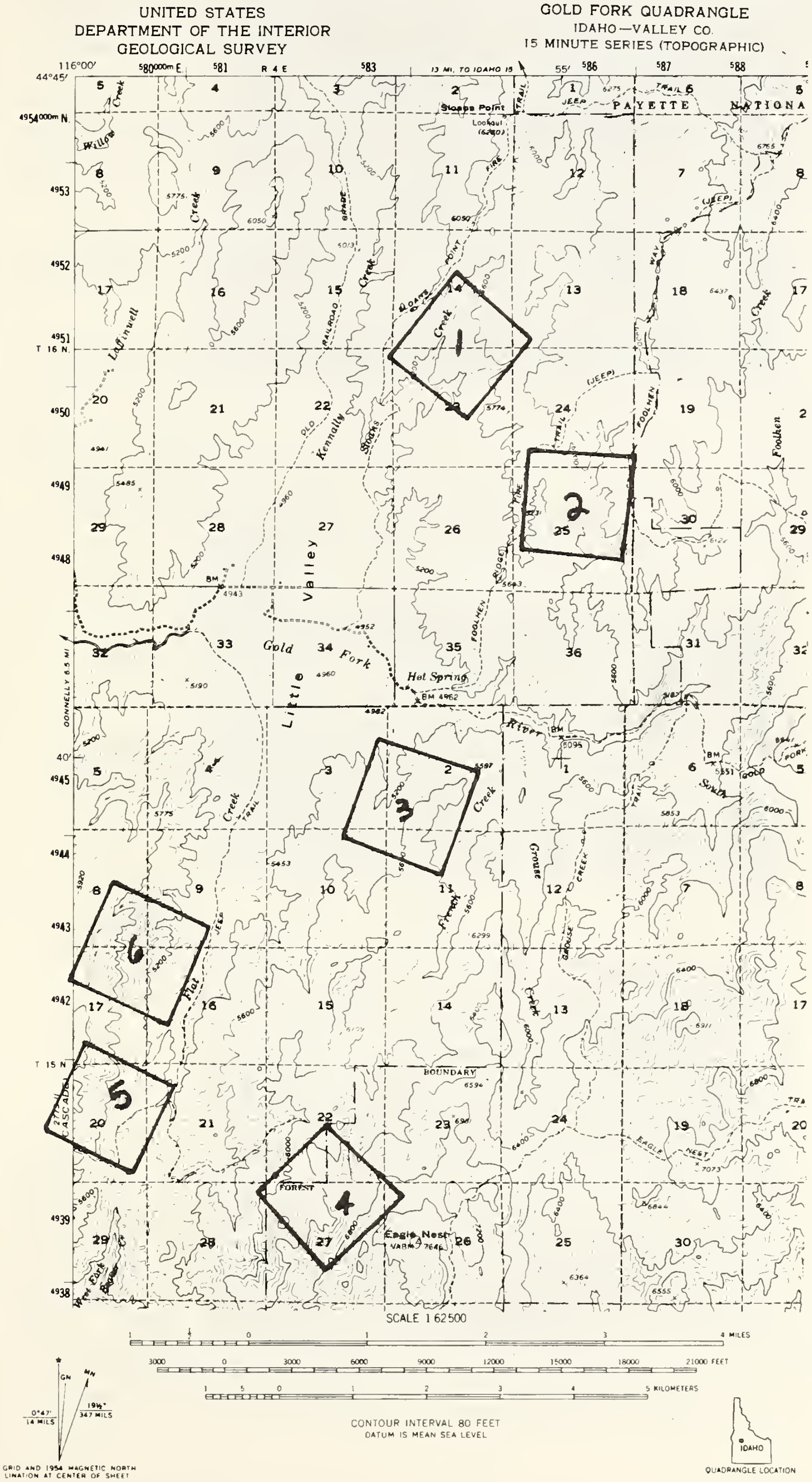


Figure 5. Location of spray blocks, overlayed on 80-foot contour interval topographic map. Turbo Thrush test, Idaho 1978.



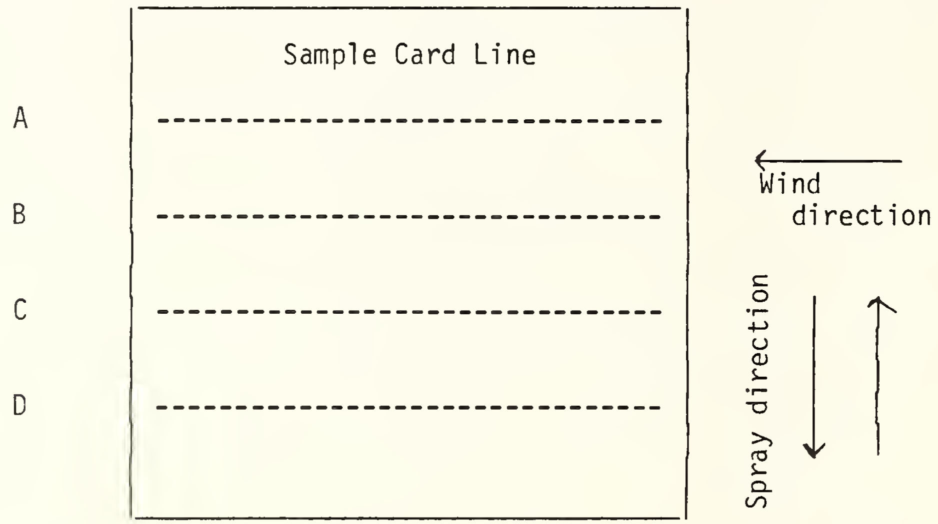
One Bell 206B Jet Ranger owned by Idaho Helicopters, Boise, Idaho. This aircraft was the chase aircraft for monitoring fixed- and rotor-wing spray ships performance, and was also used for marking corners of spray blocks and for emergency evacuation.

One Marsh Turbo Thrush owned by Mountain Air Spray Company, Craig, Colorado. This fixed-wing jet-prop powered (Garrett TPE-331) spray aircraft was the primary test vehicle (Fig. 1).

One Cessna 206 fixed-wing aircraft, furnished by USDA-FS Missoula Equipment Development Center (MEDC). This aircraft was used to photograph spray operations.

One pair of blocks was sprayed each morning, one block by the Jet Ranger and one by the Turbo Thrush. The following day the same pair was sprayed, each aircraft spraying the other block.

Figure 6. Spray block diagram. Kromekote card sample line, one card every 75 feet. Spray block was 500 acres, measuring 4667 x 4667 feet. Turbo Thrush test, Idhao 1978.



Both aircraft were calibrated at the McCall airport to deliver the one-half gallon per acre. The Jet Ranger (Figs. 3, 7, 8) was calibrated by capturing spray from a nozzle on each end of the spray boom and comparing the captured volume to time. The Turbo Thrush, with a propeller-driven Root pump system (Fig. 9), was calibrated by measuring the volume required to refill the hopper to its original level after one minute of airborne spraying. New Spraying Systems Company nozzles, screens, and tips were used on both aircraft. The Turbo Thrush was equipped with 18 TeeJet Flat Fan 8015 nozzle tips and the Jet Ranger with 28 Flat Fan 8003 tips. In an attempt to achieve a smaller drop size with the Jet

Figure 7. Spray boom on Jet Ranger. Turbo Thrush test, Idaho 1978.

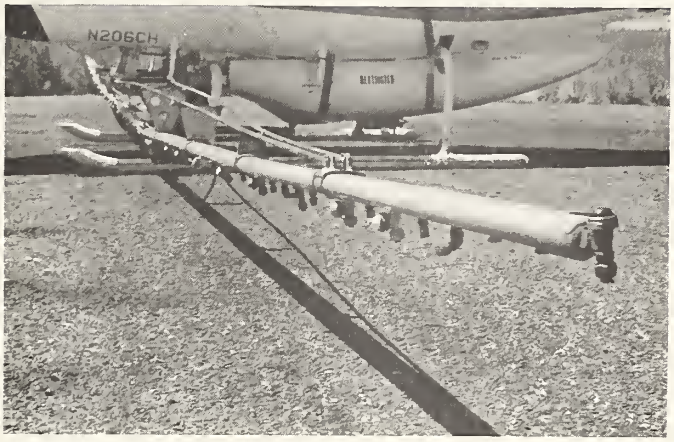


Figure 8. Spray boom on Jet Ranger. Note "Automatic Flagman" dispenser near fuselage. Turbo Thrush test, Idaho 1978.

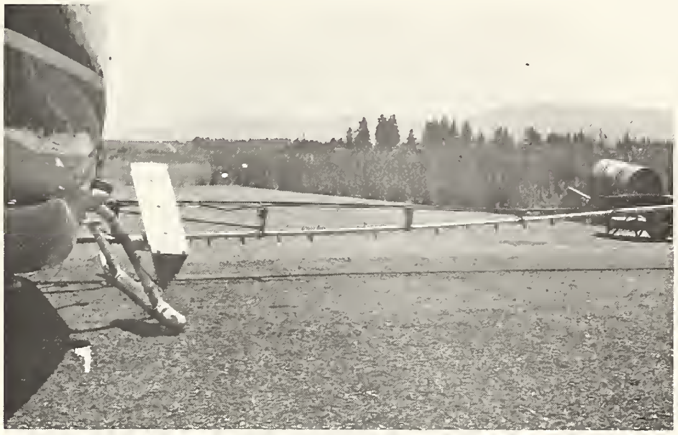
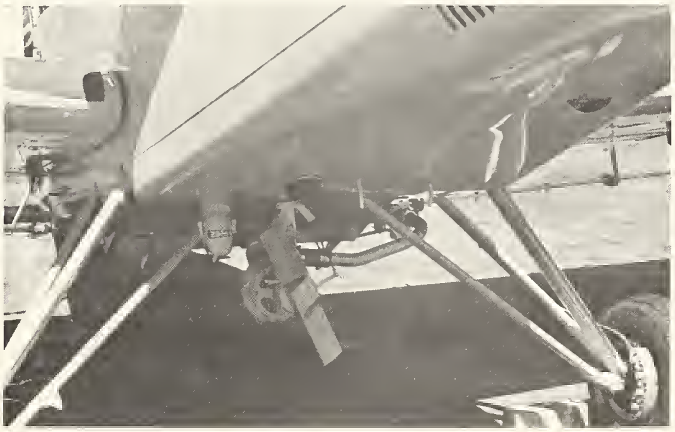


Figure 9. Wind-driven pump mounted on Turbo Thrush. Turbo Thrush test, Idaho 1978.



Ranger, smaller nozzle tips were installed after blocks 5 and 6 were sprayed. The first two blocks were sprayed with 8006 tips; thereafter we used 8003 tips. This reduced the droplet size (VMD) but not significantly (Table 2). Spray equipment, spray boom, nozzle type, and their relative positive on the aircraft are shown in Figures 10, 11, and 12.

Table 1. Operating parameters for spray aircraft. Turbo Thrush test, Idaho 1978.

Factor	Jet Ranger	Turbo Thrush
Speed (mph)	80	150
Spray altitude above canopy (ft.)	50	50
Swath width (ft.)	120	200
Nozzle tip[1]	Spraying Systems TeeJet Flat Fan 8003	Spraying Systems TeeJet Flat Fan 8015
Nozzle orientation	Down	Down
Number nozzles	28	18
Boom pressure (psig)	35	40
Application rate (ounces/acre)	64	64
Application (ounces/minute)	1228.8	3840
Application (acres/minute)	19.2	60
Flow rate factor	1.14	1.14
Payload (gallons)[2]	63	400

1 Jet Ranger used 14 each 8006 nozzle tips to spray blocks 5 and 6. Information provided in table is for 8003 nozzle tips only.

2 Spray tank (hopper) of the Turbo Thrush was filled to 375 gallons each morning prior to dispatch to spray block.

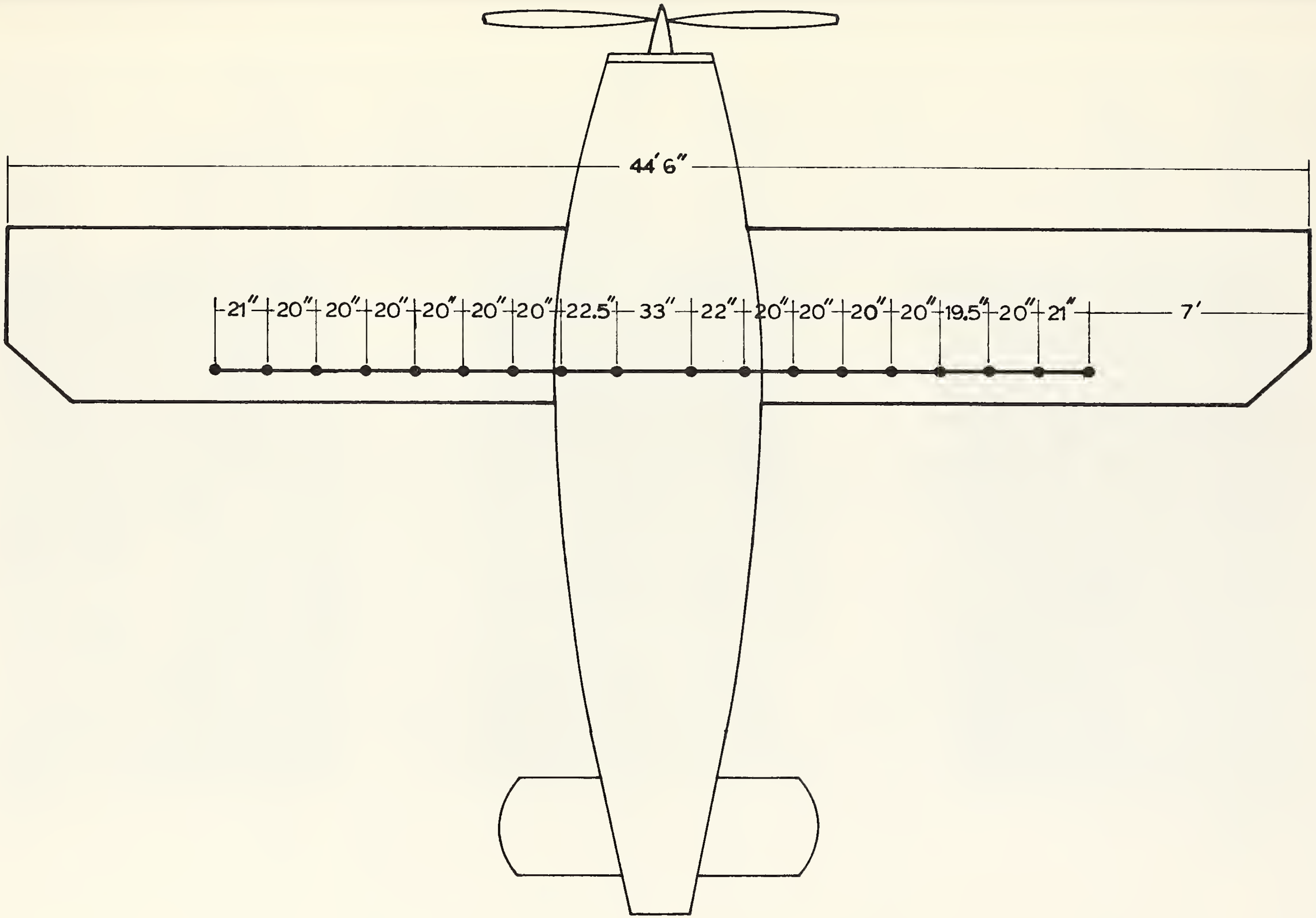


Figure 10. Relative spacing of Spraying Systems Co. 8015 nozzles on Turbo Thrush underwing boom. Turbo Thrush test, Idaho 1978.

Table 2. Spray characterization for drop size as expressed by volume median diameter for Turbo Thrush and Jet Ranger, conducted at McCall, Idaho, airport. Turbo Thrush test, Idaho 1978.

Trial	Aircraft	Nozzle tip	Volume median diameter (μm)
1	Jet Ranger	8006	243
2	Jet Ranger	8006	253
3	Turbo Thrush	8015	145
4	Jet Ranger	8003	237
5	Jet Ranger	8003	230

Spray characterization consisted of both aircraft flying 50 feet above a sampling line of Kromekote® cards. In addition to providing information on drop size, this procedure provided an operational check of the spray system.

Table 3 shows the sequence in which each block was sprayed. On the first day the Turbo Thrush and the Jet Ranger sprayed blocks 5 (Saddle) and 6 (John's), approximately one-half mile apart. As spraying progressed, it became obvious that the wide turning radius of the Turbo Thrush was overlapping the Jet Ranger's turning radius. This was a potentially dangerous situation and both pilots were advised of their close proximity. Spraying continued with the pilots advising each other of their respective positions. This incident pointed out that fixed- and rotor-wing operations should not be carried out simultaneously when turning patterns conflict. For this test it was a simple matter of staggering spray start times for the Turbo Thrush and the Jet Ranger to provide adequate airspace separation.

One of the primary tasks of the demonstration was to determine if the fixed-wing Turbo Thrush could fly terrain following profiles which helicopters can negotiate with relative ease. Two assessment techniques were utilized: visual observation of flight patterns from vantage points on the ground, and actual chase of the Turbo Thrush with a helicopter to observe flight performance above the forest canopy.

Spray Deposit Sampling

Four spray deposit card lines were established in each block (Fig. 6). Lines were 933 feet apart and perpendicular to the expected flight path. A sample site (Fig. 13) was selected every 75 feet along each card line unless the point fell on or within one foot of a tree trunk,

Figure 11. Spray boom, right side of Turbo Thrush. Vertical nozzles used on test. Turbo Thrush test, Idaho 1978.

Figure 12. Spraying Systems Co. Flat Fan nozzles on Turbo Thrush. Vertical nozzles used on test. Turbo Thrush test, Idaho 1978.

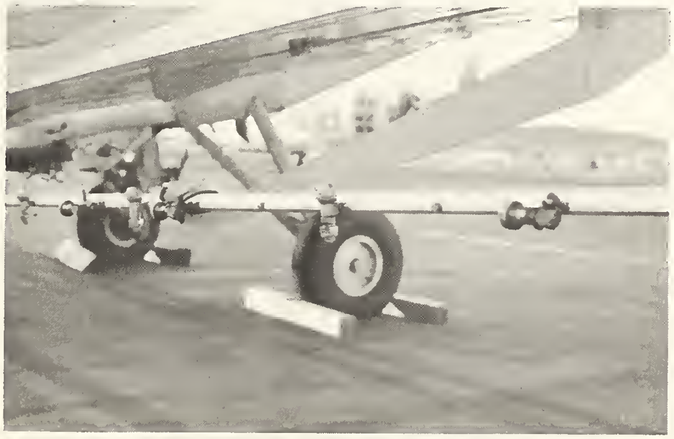


Figure 13. Kromekote card in holder at stake position A-1. A is sampling A and 1 is the first sampler in line A. Turbo Thrush test, Idaho 1978.

Table 3. Spray block identification and spray sequence. Turbo Thrush test, Idaho 1978.

Block No.	Block name	Date Sprayed	Aircraft
5	Saddle	7-29	Turbo Thrush
6	John's	7-29	Jet Ranger
6	John's	7-30	Turbo Thrush
5	Saddle	7-30	Jet Ranger
2	Hot Spring	7-31	Turbo Thrush
1	Sloan's Point	7-31	Jet Ranger
1	Sloan's Point	8-1	Turbo Thrush
2	Hot Spring	8-1	Jet Ranger
4	French Creek	8-2	Turbo Thrush
3	Eagle Nest	8-2	Jet Ranger
3	Eagle Nest	8-3	Turbo Thrush
4	French Creek	8-3	Jet Ranger

in which case the site was moved a foot or two in any direction. Clinometers were used for slope compensation so the distance between sample sites was a horizontal distance, not a slope distance. At each sample site a 1 x 2-inch wooden stake, three feet high, was used to hold a deposit card sampler. The card line number and sample number were marked on each stake. Standard Kromekote spray deposit cards were positioned just before spray application (Fig. 13).

Upon completion of the field testing, deposit cards were sent to Los Alamos Scientific Laboratory, New Mexico, where they were assessed on the Quantimet Image Analyzer.

Meteorology

A meteorological station was established in or immediately adjacent to each spray block. Meteorological readings were taken at 15-minute intervals starting one-half hour before spraying and continuing for

one-half to one hour after spraying. Temperatures were measured at ground surface level, five feet, and 100 feet, by a telethermometer sensing unit suspended from a meteorological balloon. Relative humidity was calculated from dry and wet bulb measurements. On each spray day the wind speed on one of the blocks was measured at the five-foot level with a wind gauge capable of recording speeds as low as 10 feet per minute. On the other block being sprayed wind speed was estimated by determining the length of time it took a small puff of smoke to move a predetermined distance. Wind at the 100-foot level was measured by determining the angle of lean of the meteorological balloon and finding the windspeed from a conversion table. At the beginning, middle, and end of spraying, a smoke bomb was released and observations made on smoke behavior.

For five of the six blocks spraying was conducted under what are generally considered optimum conditions, i.e., temperatures less than 65° and light downslope winds. Exceptions to this were both times block 4, Eagle Nest, was sprayed. On the first day of spraying winds averaging 5 to 6 mph with gusts to 10 mph were blowing from northeast to southwest over the high central ridge; these were gradient as opposed to drainage winds. However, wind conditions either side of the ridge were 3 to 4 mph. The observation helicopter reported that the winds above the main ridge and some of the other high points in this block were quite turbulent. The next day ridge winds had declined and spray conditions were more favorable. Unfortunately, a leak in the Jet Ranger spray boom caused a 45-minute delay in start of spraying, and although conditions were ideal at the start of spraying, the temperature began to rise rapidly. The inversion broke before the spraying was completed. Therefore, while the spray had been settling well during the first half of the operation, during the second half the spray cloud hung in the air and did not settle. Examination of deposit data for the Eagle Nest block should take these factors into consideration, as we believe that both aircraft sprayed under less than favorable meteorological conditions.

RESULTS

Results of this demonstration are represented by both quantitative data analysis and qualitative observations. In view of the fact that this project was to demonstrate the suitability of the Marsh Turbo Thrush to deliver pesticides to coniferous forests, there was no intent to conduct an extensive test to measure all possible variables, particularly variables associated with pilot qualification and spray mission economics. As discussed earlier, a Jet Ranger, which the FS has used many times in the past for forest spraying, was used as a standard for base line reference. Knowing what to expect from the Jet Ranger in terms of deposition was a rational basis for evaluating the performance of the Turbo Thrush.

Meteorological data are given in Tables 4 and 5 and results of spray deposit recoveries are given in Tables 6-10 and Figures 14-25. Analysis and discussions which follow were derived from these raw data.

Table 4. Summary of meteorological conditions during spraying by Jet Ranger. For each block first line of data represents condition at start of spraying; second line at finish. Turbo Thrush test, Idaho 1978.

Block	Date Treated	Time (am)	Temperatures (°F) Ground	Temperatures (°F) 5 ft	Temperatures (°F) 100 ft	Relative Humidity	Wind - Ground Direction	Wind - Ground Speed (ft/min)	Wind - 100 ft Direction	Wind - 100 ft Speed (ft/min)	Smoke Behavior
1	7-31	Start 7:38	47	44	44	98	0	<10	0	<30	-Hugged ground, moved down canyon
		Finish 8:30	48	46	58	98	NE	92	NE	50	- "
2	8-1	Start 7:15	43	51	55	53	NE	100	NE	50	-Stayed near ground, drifted downslope
		Finish 8:08	49	60	61	54		<10	W	<10	-Rose slowly to treetop level
3	8-2	Start 7:28	41	40	44	100	NE	<10	N	<10	-Rose slightly, drifted up valley
		Finish 8:15	43	44	50	100	NE	<10	N	<10	- "
4	8-3	Start 8:09	48	54	66	48	SE	312	E	<10	-Stayed close to ground, moved rapidly downslope
		Finish 9:01	62	59	70	52	SE	<10	E	<10	-Straight up to twice tree height
5	7-30	Start 7:14	40	44	55	100	-	0	-	0	-Stayed close to ground, same area for 5 min.
		Finish 8:15	50	52	64	100	N	120	NE	50	-Stayed 3-5 ft from ground, moved toward south
6	7-29	Start 7:40	53	50	54	90	E	<10	E	<10	-Hugged ground, moved slowly uphill to west
		Finish 8:30	55	55	59	88	E	<10	E	10	"

Table 5. Summary of meteorological conditions during spraying by Turbo Thrush. For each block first line of data represents condition at start of spraying; second line at finish. Turbo Thrush test, Idaho 1978.

Block	Date Treated	Time (am)	Temperatures (°F) Ground	5 ft	100 ft	Relative Humidity	Wind - Ground Direction	Speed (ft/min)	Wind - 100 ft Direction	Speed (ft/min)	Smoke Behavior
1	8-1	Start 7:38	44	40	42	100	NE	100	NE	10	-Hugged 2-3 ft above ground, moved downslope
		Finish 8:00	45	41	49	94	NE	50	NE	30	- "
2	7-31	Start 7:57	52	60	64	60	NE	10	NE	10	-Rose to tree tops, then drifted downslope
		Finish 8:18	54	62	65	56	NW	10	NE	87	-Rose above tree tops
3	8-3	Start 7:56	42	40	46	84	S	10	-	0	-Climbed 20 ft, drifted downslope
		Finish 8:18	43	41	47	82	NE	10	NE	10	-Stayed 30 ft above ground, drifted upslope
4	8-2	Start 8:09	50	58	60	42	E	224	NE	5 mph gust to 10 mph	-Hugged ground, moved quickly downslope
		Finish 8:41	50	60	68	38	NE	160	NE	6 mph gust to 10 mph	-Variable
5	7-29	Start 8:17	54	55	62	89	SW	82	-	0	-Stayed close to ground, movement variable
		Finish 8:40	56	59	65	84	Variable	up to 100	NE	243	-Moved up into canopy
6	7-30	Start 7:52	49	47	55	92	E	10	E	120	-Rose to 10 ft, then drifted uphill
		Finish 8:15	50	48	56	92	E	20	E	120	- "

Table 6. Number of spray droplets (per cm^2) recovered on Kromekote cards, by spray block and sampling line for both Turbo Thrush and Jet Ranger. Turbo Thrush test, Idaho 1978.

Turbo Thrush

Block	Line A	B	C	D	Mean
1	3.1	7.6	12.5	21.7	11
2	15.6	19.2	15.0	9.4	14
3	25.2	25.7	28.4	26.7	26.5
4	7.9	9.0	8.8	12.4	9.5
5	11.7	14.1	19.7	16.1	15.5
6	32.8	28.4	25.3	28.3	28.7
Combined Means					17.5
S.E.					3.3

Jet Ranger

Block	Line A	B	C	D	Mean
1	6.9	5.5	8.9	11.1	8
2	10.7	12.0	14.5	8.5	11.3
3	13.6	11.8	9.9	10.0	11.3
4	12.7	9.3	10.8	11.5	11.0
5	10.7	8.8	13.1	15.5	12.0
6	15.4	15.1	14.1	15.4	15.0
Combined Means					11.43
S.E.					0.91

Table 7. Volume median diameter (μm) by spray block and sampling line for both Turbo Turbo Thrush and Jet Ranger. Turbo Thrush test, Idaho 1978.

Turbo Thrush

Block	Line A	B	C	D	Mean
1	147	125	130	116	125
2	129	125	127	131	128
3	127	134	139	141	136
4	128	158	163	155	155
5	131	122	136	135	132
6	131	134	122	134	131
Combined Means					134
S.E.					4.37

Jet Ranger

Block	Line A	B	C	D	Mean
1	297	266	278	270	279
2	290	281	274	281	282
3	253	229	256	264	253
4	264	271	292	275	275
5	286	279	267	279	278
6	270	269	280	288	277
Combined Means					274
S.E.					4.36

Table 8. Volume recoveries (gallons per acre) on Kromekote cards by spray block and sampling line for both Turbo Thrush and Jet Ranger. Turbo Thrush test, Idaho 1978.

Turbo Thrush

Block	Line A	Line B	Line C	Line D	Mean
1	.022	.029	.041	.072	.041
2	.061	.052	.048	.038	.049
3	.067	.074	.109	.107	.089
4	.030	.067	.059	.082	.059
5	.040	.041	.070	.065	.054
6	.096	.089	.071	.105	.091
Combined Means					.064
S.E.					.009

Jet Ranger

Block	Line A	Line B	Line C	Line D	Mean
1	.131	.083	.108	.151	.118
2	.149	.138	.148	.125	.140
3	.110	.101	.113	.136	.115
4	.116	.159	.136	.158	.142
5	.171	.128	.160	.212	.168
6	.192	.188	.188	.221	.197
Combined Means					.147
S.E.					.013

Table 9. Number mean diameter (μm) by spray block and sampling line for both Turbo Thrush and Jet Ranger. Turbo Thrush test, Idaho 1978.

Turbo Thrush

Block	Line A	Line B	Line C	Line D	Mean
1	85	72	66	69	73
2	72	61	65	72	68
3	60	61	68	69	65
4	70	89	81	84	81
5	56	63	66	70	64
6	62	63	63	68	64
Combined Means					69
S.E.					2.75

Jet Ranger

Block	Line A	Line B	Line C	Line D	Mean
1	98	92	85	90	91
2	87	81	77	92	84
3	73	78	85	91	82
4	75	102	82	90	87
5	92	91	84	86	88
6	84	85	87	89	86
Combined Means					86
S.E.					1.28

Table 10. Number median diameter (μm) by spray block and sampling line for both Turbo Thrush and Jet Ranger. Turbo Thrush test, Idaho 1978.

Turbo Thrush

Block	Line A	Line B	Line C	Line D	Mean
1	89	68	59	64	70
2	66	53	58	66	61
3	51	51	58	60	55
4	65	85	71	77	75
5	58	56	57	62	58
6	52	53	58	60	55
Combined Means					62
S.E.					3.40

Jet Ranger

Block	Line A	Line B	Line C	Line D	Mean
1	71	66	64	70	68
2	64	62	59	70	63
3	57	61	64	70	63
4	57	82	61	68	67
5	66	69	63	63	65
6	62	64	63	66	64
Combined Means					65
S.E.					0.86

Figure 14. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 5 sprayed by the Turbo Thrush. Turbo Thrush test, Idaho 1978.

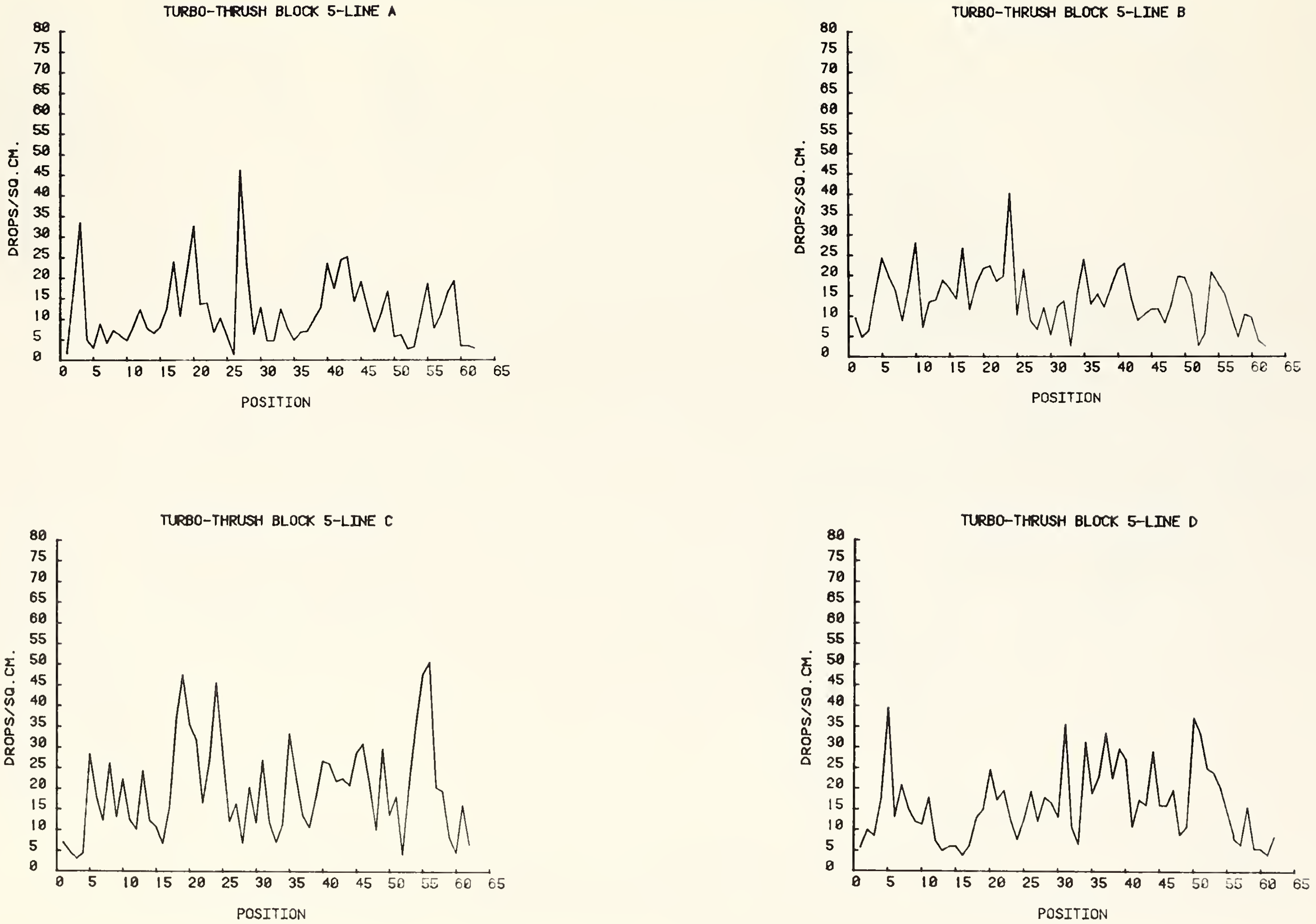


Figure 15. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 6 sprayed by the Turbo Thrush. Turbo Thrush test, Idaho 1978.

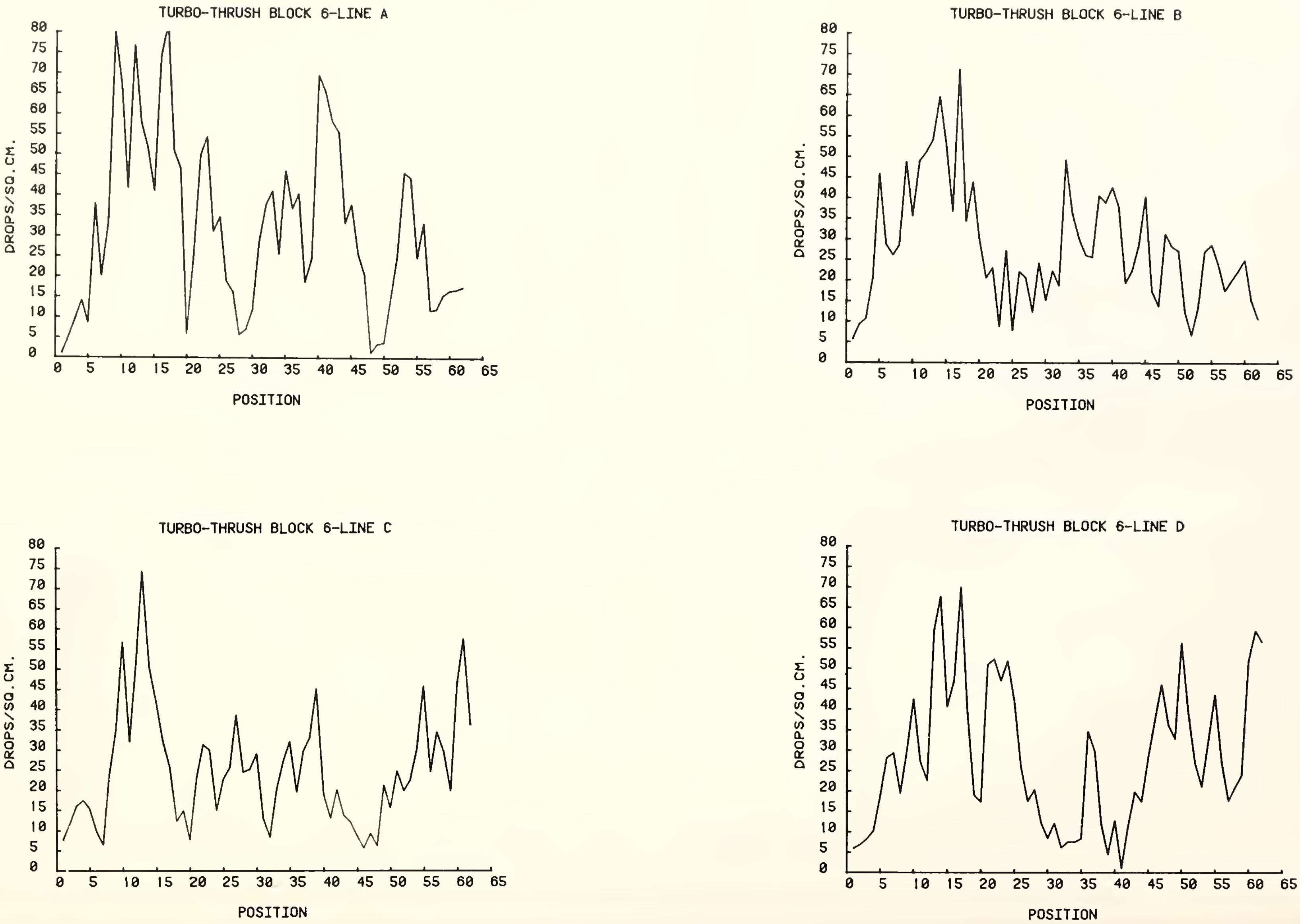


Figure 16. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 2 sprayed by the Turbo Thrush. Turbo Thrush test, Idaho 1978.

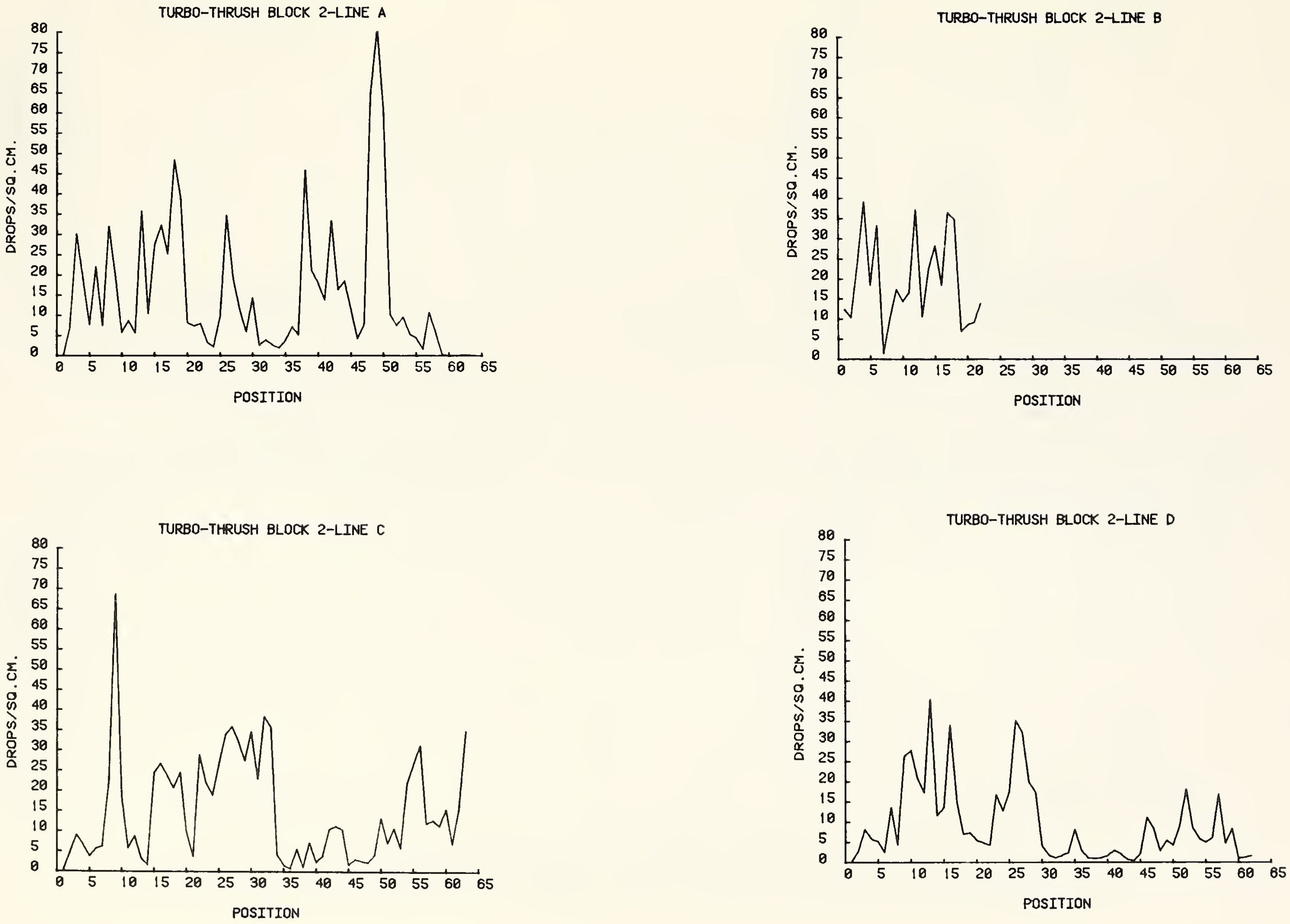


Figure 17. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 1 sprayed by the Turbo Thrush. Turbo Thrush test, Idaho 1978.

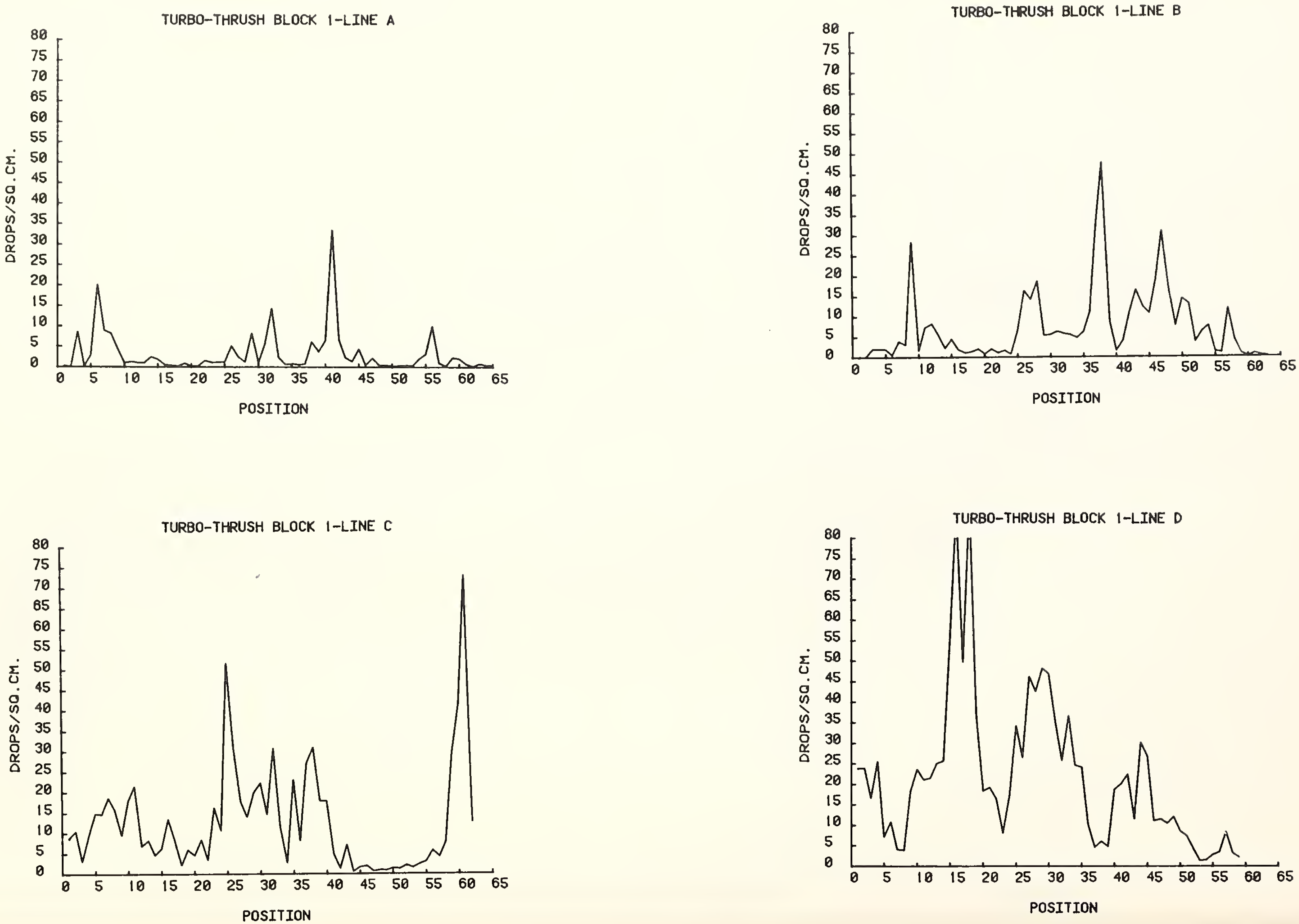


Figure 18. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 4 sprayed by the Turbo Thrush. Turbo Thrush test, Idaho 1978.

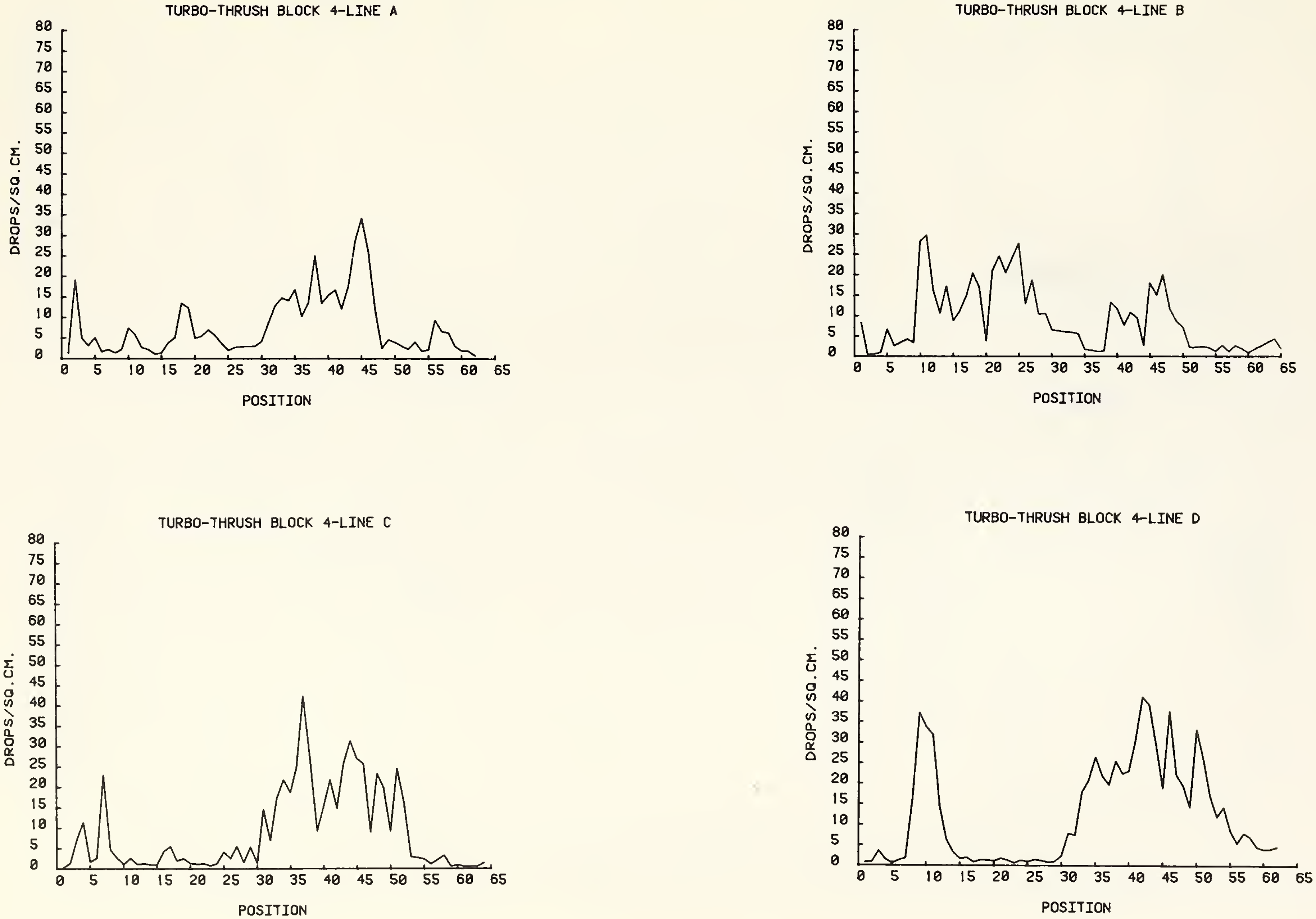


Figure 19. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 3 sprayed by the Turbo Thrush. Turbo Thrush test, Idaho 1978.

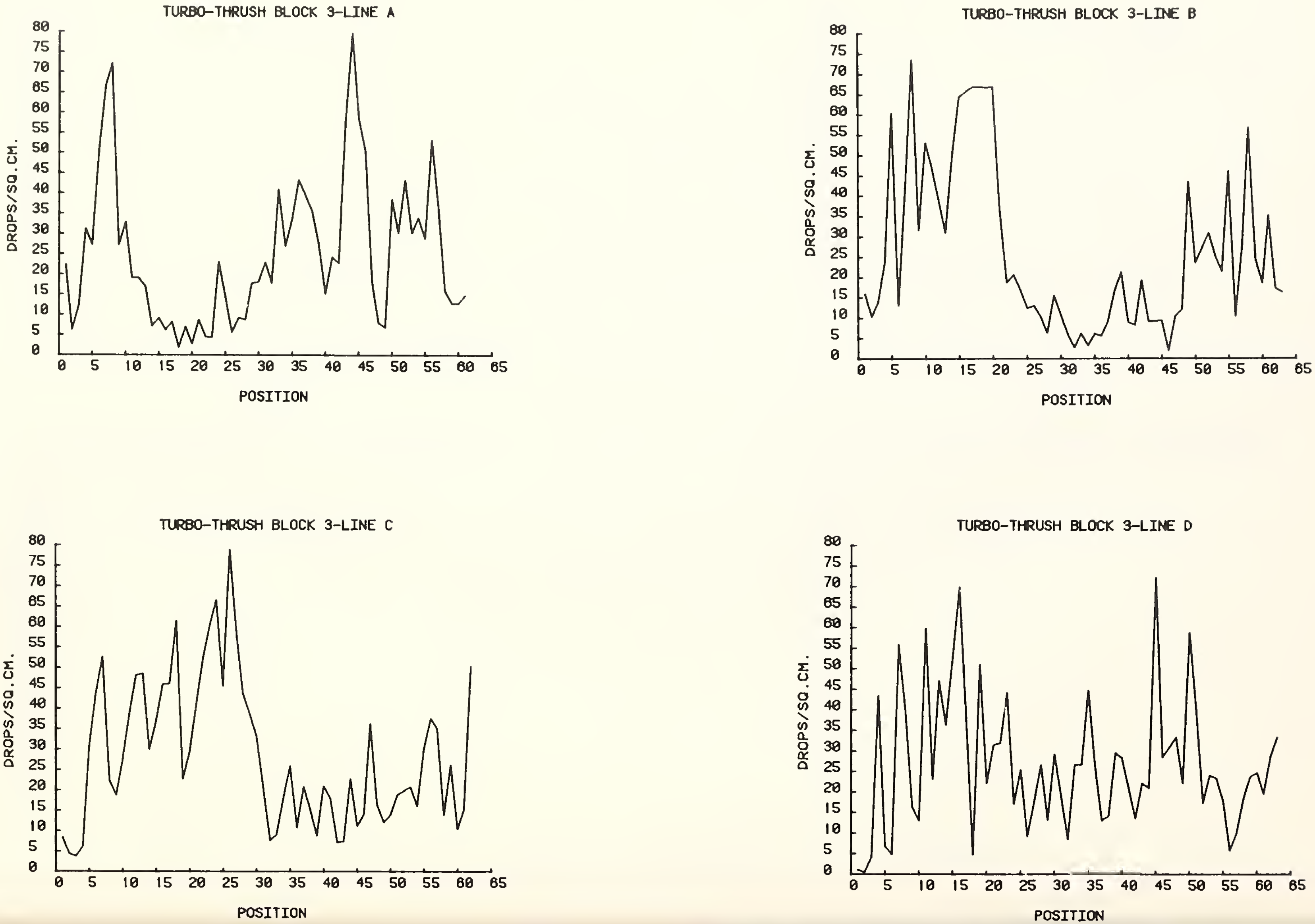


Figure 20. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 6 sprayed by the Jet Ranger. Turbo Thrush test, Idaho 1978.

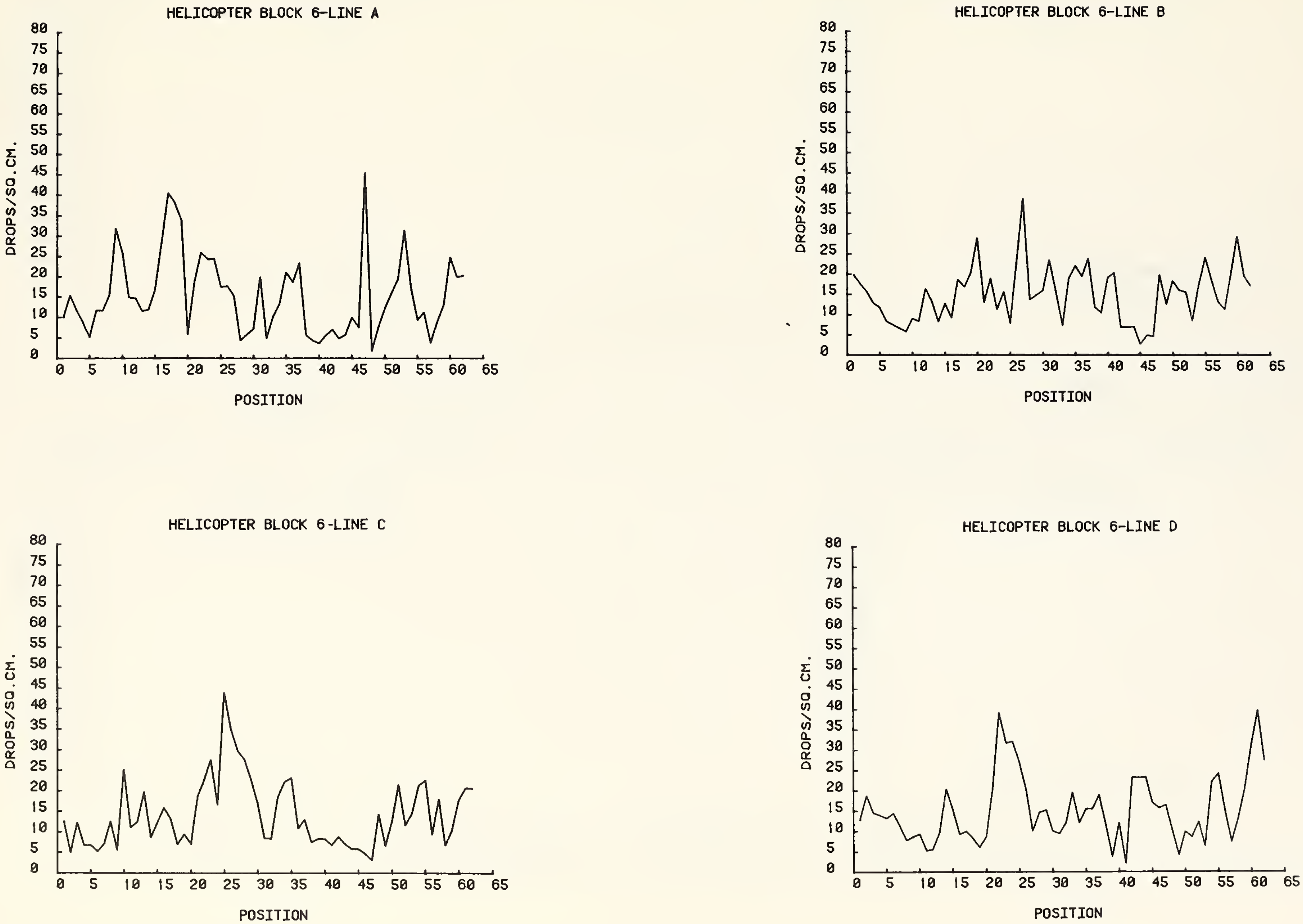


Figure 21. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 5 sprayed by the Jet Ranger. Turbo Thrush test, Idaho 1978.

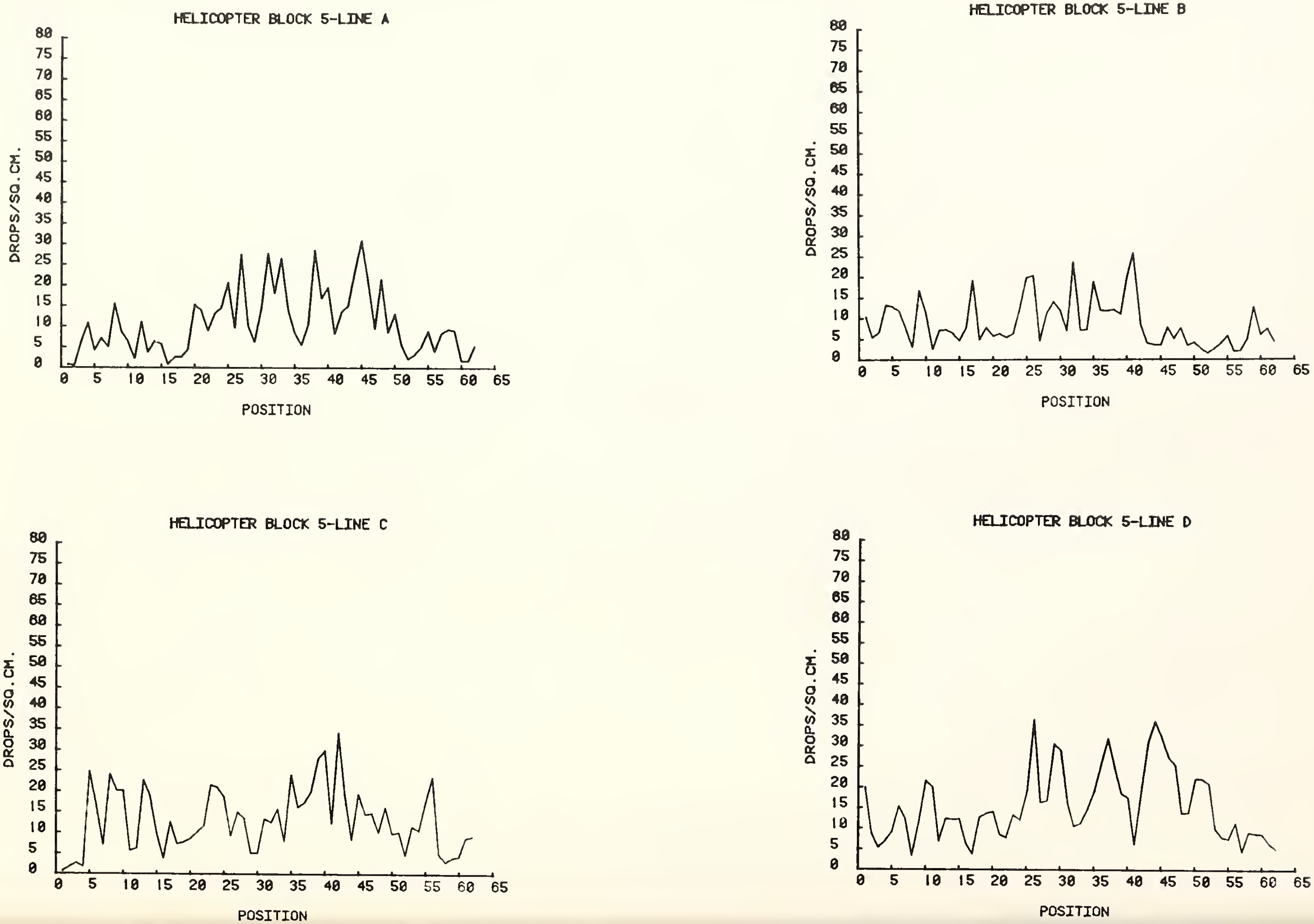


Figure 22. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 1 sprayed by the Jet Ranger. Turbo Thrush test, Idaho 1978.

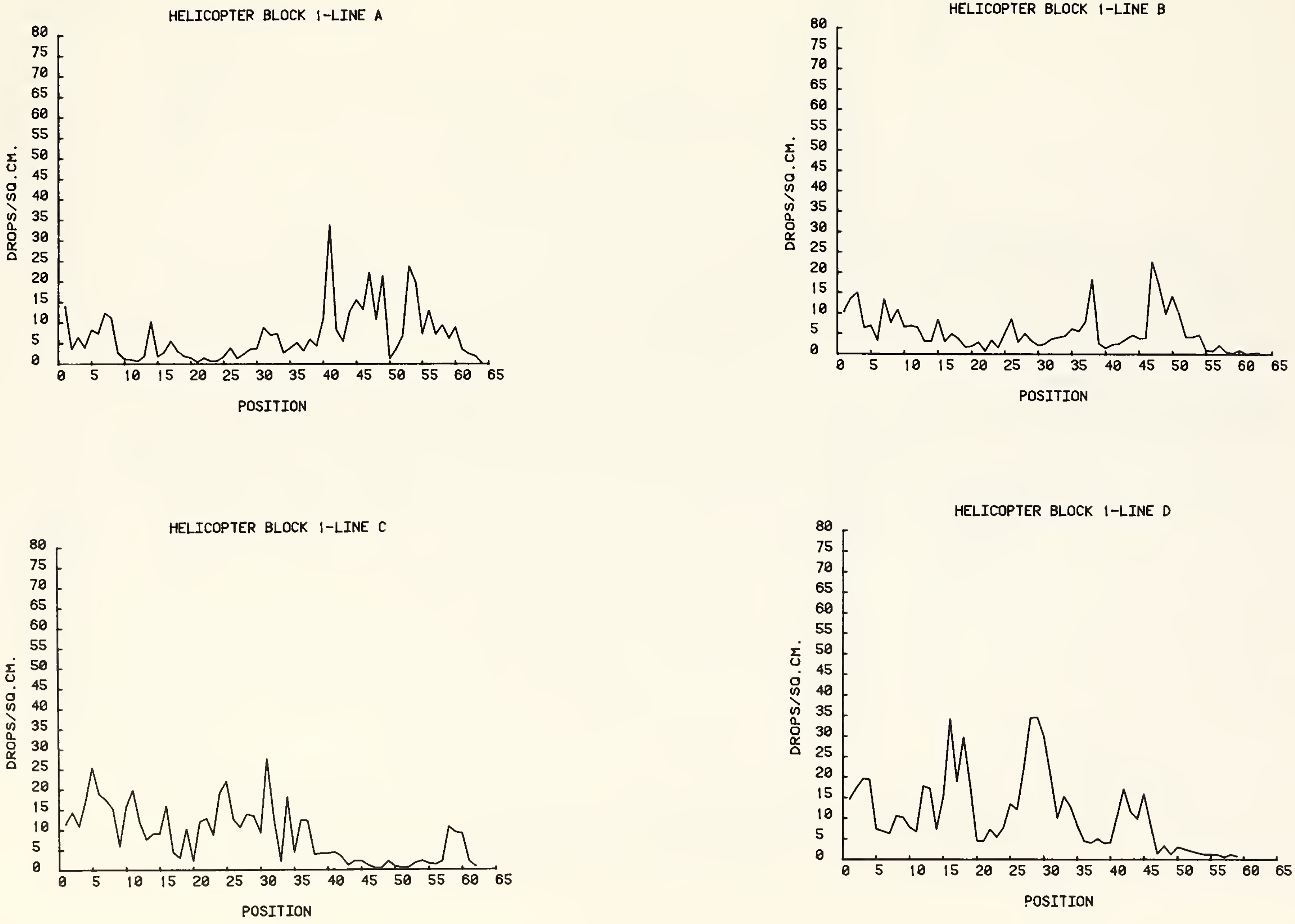


Figure 23. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 2 sprayed by the Jet Ranger. Turbo Thrush test, Idaho 1978.

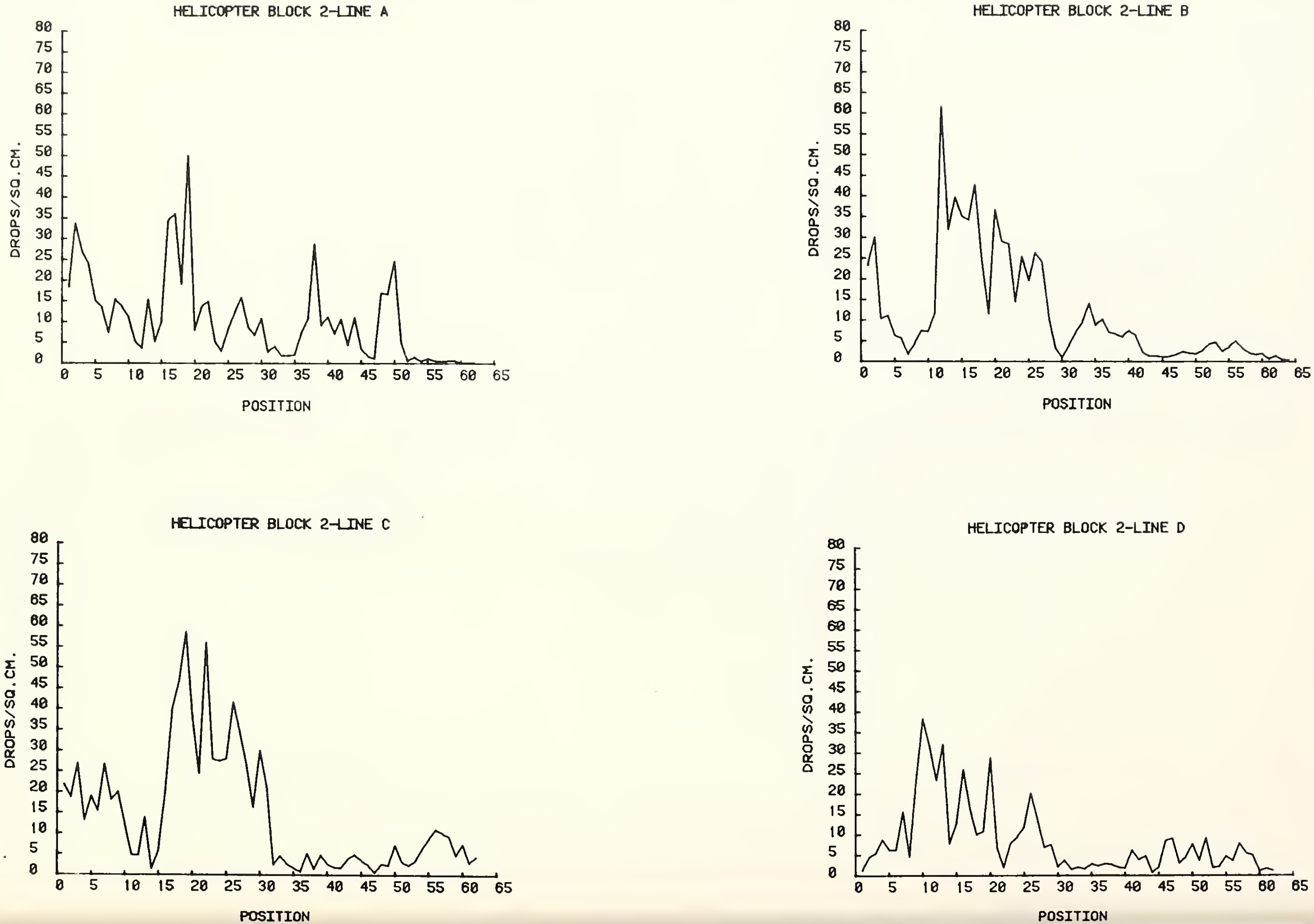


Figure 24. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 3 sprayed by the Jet Ranger. Turbo Thrush test, Idaho 1978.

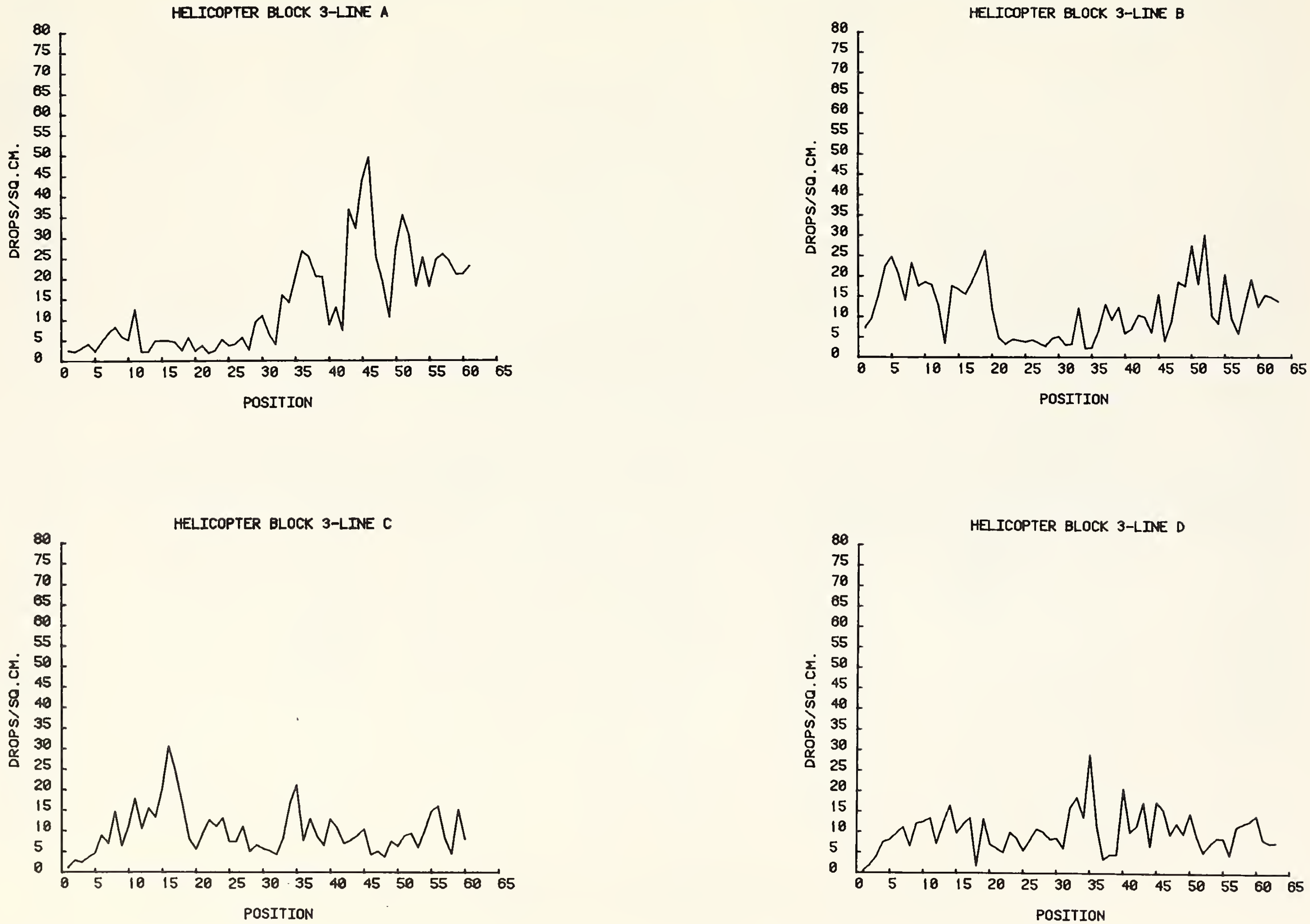
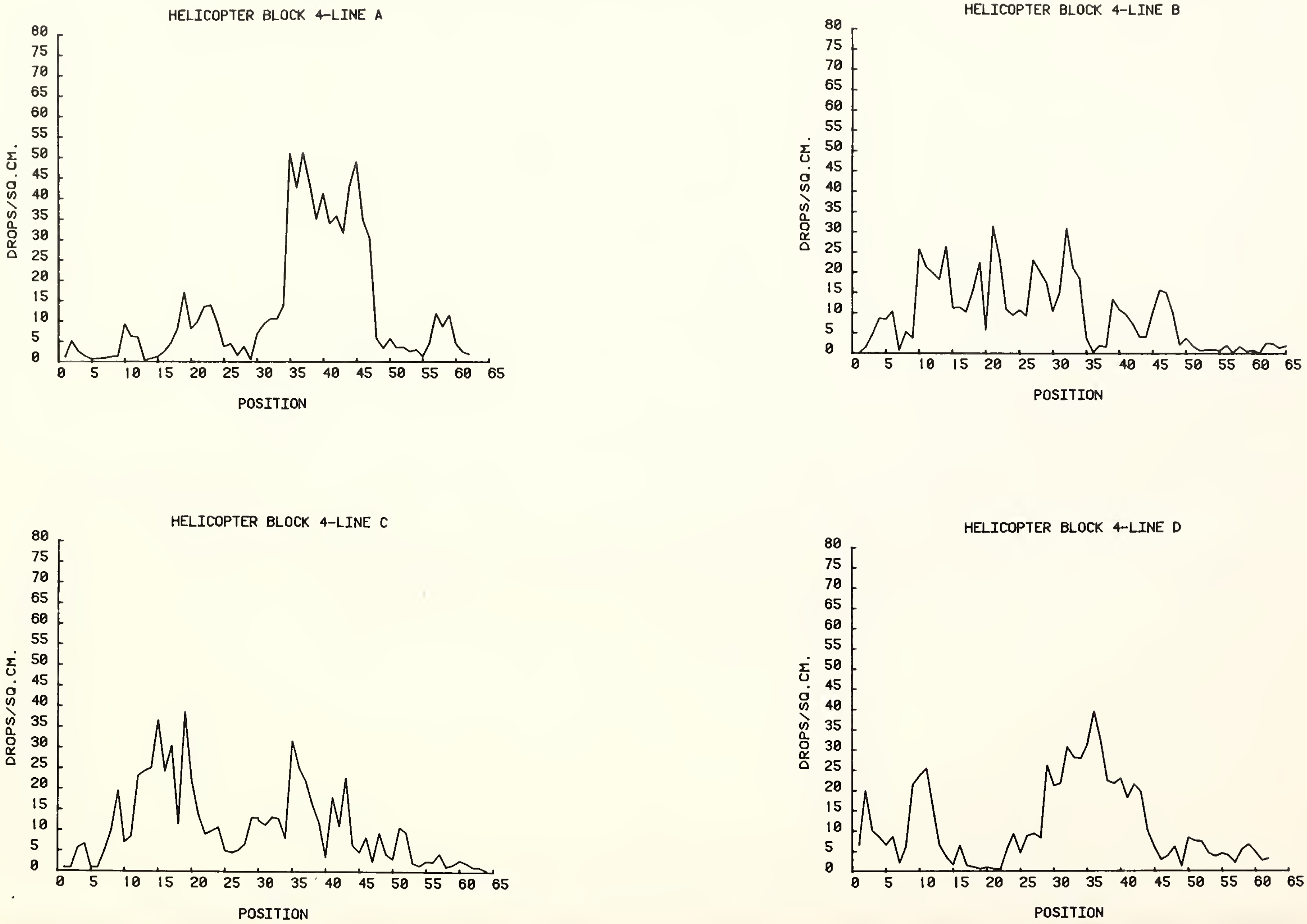


Figure 25. Spray droplets recovered at each of the 65 sampling stations along the four sampling lines (A, B, C, D) which ran perpendicular to the spray swaths, for Block 4 sprayed by the Jet Ranger. Turbo Thrush test, Idaho 1978.



Qualitative observations are based upon ground and aerial observations by personnel conducting and supporting the project (Tables 11-13).

Quantitative Results

Performance analysis of the Turbo Thrush relative to the Jet Ranger consisted of evaluating each of the five performance variables or indicators obtained from deposit cards: drops/cm^2, mass recovery, volume median diameter (VMD), number mean diameter, and number median diameter. Each block sprayed by each aircraft was treated as a sampling unit. Block means and standard errors for these variables are tabulated in Tables 6-10. Figures 14-25 present a graphic display of the spray deposition along the perpendicular sampling lines.

Utilizing the information in Tables 6-10, two separate analyses were conducted. The first analysis was a determination of whether both aircraft were equally consistent in their performance from trial to trial. the second analysis was a determination of whether both aircraft performed equally well primarily in terms of the number of droplets deposited, VMD, and the recovered.

In the first analysis, that of consistency of performance, we tested the ability of an aircraft to perform consistently from block to block. The statistical approach was to determine first whether S_H^2 (sample variance for the Jet Ranger) and S_T^2 (sample variance for the Turbo Thrush) were from normal populations with the same variance (null hypothesis). The alternative is a one-sided test, either $S_T^2 > S_H^2$ or $S_H^2 > S_T^2$. Following a procedure described by Snedecor and Cochran (1968), our test statistic was the F distribution expressed as the ratio of the two sample variances, S_T^2 and S_H^2, with the larger variance term appearing in the numerator. The computed test statistic was compared to the critical value, for a one-sided test with five degrees of freedom for each sample, at a five percent significance level.

We concluded from this analysis that the variation in the number of droplets from block to block was greater for the Turbo Thrush than for the Jet Ranger. However, variation in VMD and mass recovery were determined to be the same (Table 14).

Our next analysis was a test of significance for the difference between the means for the six blocks for each of the five variables. The test statistics, as described in Snedecor and Cochran (1968), was Student's t distribution, i.e.,

$$t - \bar{d}/ \sqrt{S_H^2/n_H + S_T^2/n_T}$$

where $\bar{d}$ is the difference between the two sample means (Jet Ranger block to Turbo Thrush block). Our test statistics were computed from the above and compared to the critical value for a two-tailed test obtained from the t table with n-1 degrees of freedom where $n = n_H =$

Table 11. Comparison of spray time per block for Turbo Thrush and Jet Ranger. Turbo Thrush test, Idaho 1978[1].

Date	Turbo Thrush Spray Time/ Block (min.)	Jet Ranger Spray Time/ Block (min.)
7-29	23	50
7-30	23	59
7-31	21	52
8-1	22	53
8-2	32	47
8-3	22	52
Mean	24	52

1 These figures do not reflect average ferry times between McCall and the spray blocks. For the Turbo Thrush operating out of McCall, an additional 16-minute average round trip time was recorded. The Jet Ranger operating from Gold Fork Helispot averaged six minutes for a round trip ferry flight.

Table 12. Field observation of performance for Jet Ranger and Turbo Thrush. Turbo Thrush test, Idaho 1978.

Aircraft	Payload[1]	Spraying Speed	Range Mean Time for Single Turn	Mean Time to Spray Block[2]
Jet Ranger	63 gal.	73-77 mph	7.8-12.5 min.	52 min.
Turbo Thrush	375 gal.	118-157 mph	28.8-45.1 min.	24 min.

1 Payload is amount of tank mix aircraft carried. Turbo Thrush carried 300 gallons only on first block spayed.

2 This is the total time required to spray a block starting at beginning of first spray swath to end of last swath.

Table 13. Summary of performance for Jet Ranger and Turbo Thrush. Figures in parenthesis are standard errors (SE). No observations were made on block 3. Turbo Thrush test, Idaho 1978.

Block	Total no. of swaths applied	No. of complete swaths accurately observed	Average swath width (ft)[1]	% From expected	Mean time to spray a swath (SE)[2]	Average spraying speed (mph)	Mean Spray Speed Uphill	Mean Spray Speed Downhill	Mean Spray Speed % Diff.	Mean time for turns (sec)(SE)	Mean time to spray swath and turn (SE)	Total time spray on (min)	Flow rate GPM
Jet Ranger													
1	37	19	126.1	24.6	43.2 (.6)	73.7	72.5	74.6	2.9	10.3 (.7)	54.9 (1.3)	25.9	9.6
2	36	26	129.6	26.1	43.9 (.5)	72.5	71.4	73.6	3.0	12.5 (.4)	56.4 (.6)	27.1	9.8
4	36	29	129.6	29.6	43.1 (.7)	73.8	--[3]	--	--	11.5 (.3)	54.6 (.8)	25.7	9.7
5	42	29	111.1	11.1	41.2 (.6)	77.2	74.2	75.4	1.5	9.6 (.2)	51.1 (.7)	28.8	8.7
6	44	10	106.1	6.1	34.7 (.2)	91.7	--[3]	--	--	9.8 (.2)	44.5 (.2)	25.4	9.8
Turbo Thrush													
1	20	12	233.4	16.5	24.2 (.6)	131.5	125.9	139.6	10.9	38.0 (1.4)	61.7 (2.0)	8.1	30.9
2	19	16	245.6	22.5	24.9 (.4)	127.8	121.7	137.4	12.9	32.0 (1.4)	56.7 (.9)	7.9	31.9
4	19	15	245.6	22.5	24.8 (.6)	128.3	--[3]	--	--	45.1 (3.3)	71.5 (2.9)	7.8	31.8
5	19	16	245.6	16.5	26.9 (.3)	118.3	115.7[4]	133.9	15.7	28.8 (.6)	55.9 (1.1)	8.5	29.4
6	23	18	202.9	2.0	20.3 (.6)	156.8	--[3]	--	--	35.7 (1.6)	56.2 (1.9)	7.8	32.2

1 Determined by dividing block width by number of swaths applied to block.

2 Presuming cut on and off at plot boundaries.

3 No significant slope

4 Measured only on last half of plot.

Table 14. A test of the equality of variances between blocks for the Turbo Thrush (T) and the Jet Ranger (H). Turbo Thrush test, Idaho 1978.

Variables Tested	Hypothesis Tested	Test Statistic (computed)	Test Criteria (from table)	Conclusion
drops/ cm^2	$Ho:\sigma_H=\sigma_T$ $H_1:\sigma_T>\sigma_H$	F = 13.13	F = 5.05	Reject Ho
mass	$Ho:\sigma_H=\sigma_T$ $H_1:\sigma_H>\sigma_T$	2.40	5.05	Accept Ho
VMD	$Ho:\sigma_H=\sigma_T$ $H_1:\sigma_T>\sigma_H$	1.00	5.05	Accept Ho
no. mean diameter	$Ho:\sigma_H=\sigma_T$ $H_1:\sigma_T>\sigma_H$	4.59	5.05	Accept Ho
no. median diameter	$Ho:\sigma_H=\sigma_T$ $H_1:\sigma_T>\sigma_H$	15.78	5.05	Reject Ho

Table 15. A test of the difference between means for the Turbo Thrush (T) and the Jet Ranger (H). Turbo Thrush test, Idaho 1978.

Variables Tested	Hypothesis Tested	Test Statistic (computed)	Test Criteria (from table)	Conclusion
drops/ cm^2	$Ho:\mu_H=\mu_T$ $H_1:\mu_T\neq\mu_H$	t = 1.77	t = 2.57	Accept Ho
mass	$Ho:\mu_H=\mu_T$ $H_1:\mu_H\neq\mu_T$	4.79	2.57	Reject Ho
VMD	$Ho:\mu_H=\mu_T$ $H_1:\mu_T\neq\mu_H$	22.66	2.57	Reject Ho
no. mean diameter	$Ho:\mu_H=\mu_T$ $H_1:\mu_T\neq\mu_H$	5.14	2.57	Reject Ho
no. median diameter	$Ho:\mu_H=\mu_T$ $H_1:\mu_T\neq\mu_H$	0.85	2.57	Accept Ho

n_T - 6 at a five percent significance level. In this analysis, the population variances were not assumed to be equal. Results from this analysis (Table 15) show that there was no significant difference between the turbo Thrush and the Jet Ranger in terms of the mean number of drops/cm^2 and the number median diameter under the condtiions of the trials. For the other test variables, i.e., VMD, mass recovery, and number mean diameter, a difference in performance between the two aircraft was detected (Tables 7-9).

Assuming quality application (i.e., even swaths, constant elevation, etc.) by both pilots, these results were predictable. The number of droplets from a given volume of spray increases significantly as the droplet size spectrum is reduced. Depending upon atmospheric conditions and method of spray application, more spray droplets may be deposited on the target as the droplet size spectrum is reduced. Conversely, increasing the droplet size spectrum reduces the number of droplets available and the larger droplets have a higher probability of depositing on the deposit type samplers, thus contributing to higher volume recoveries.

Qualitative Observations

In the field we observed that spray deposit recoveries (drops/cm^2) were generally lower on the uphill side of the spray blocks for both the Turbo Thrush and the Jet Ranger. This observation was more apparent on blocks sprayed by the Turbo Thrush.

The Turbo Thrush produced a finer spray which was more susceptible to downslope movement. The degree tc which this occurs is influenced by drop size, steepness of terrain, and intensity of the drainage (downslope) winds. The Turbo Thrush's droplet spectrum (134 μm VMD) was smaller than that of the Jet Ranger (274 μm); thus this phenomenon was more pronounced on the Turbo Thrush blocks. From a practical viewpoint, it is important to allow for downslope movement of spray when defining spray block boundaries and planning spray swaths.

The average time required for the Turbo Thrush to spray a block was 24 minutes, for the Jet Ranger 52 minutes. These times include both spray runs and turns. The Turbo Thrush took about three times longer to complete turns than the Jet Ranger. The speed of the Turbo Thrush varied more during its spray runs than that of the Jet Ranger. Ground observers using stop watches reporting that the speed of the Turbo Thrush varied by 17 mph compared to two mph for the Jet Ranger (Tables 11-13).

Both aircraft experienced difficulty in maintaining preassigned swath spacing. This is evident when examining Figures 14-25. It also was observed that both aircraft ran out of spray material before completing the last two swaths.

Flying height above the forest canopy was not measured but rough estimates were made by observers. It appeared that both aircraft were flying at about the same altitude: when one aircraft crossed a small valley quite high the other usually went over the same valley at about the same elevation. In general it was observed that both aircraft did stay within 50 feet of the tree tops.

CONCLUSION

Results demonstrated that the Marsh Turbo Thrush is capable of conducting spray operations over forested terrain in mountains.

The Turbo Thrush deposited an average of 17.5 drops/cm^2 on the forest floor. An average of 10 drops/cm^2 usually is considered acceptable on the forest floor, and 20 drops/cm^2 in the open.

RECOMMENDATIONS

1. Selection of a spray aircraft should take into consideration requirements for the job. These include spray droplet density and drop size required to effectively treat the target insect within the target environment. Tests should be conducted with the Marsh Turbo Thrush to develop techniques to produce droplet spectra ranging from 150 µm to 300 µm volume median diameter with various registered pesticide tank mixes.

2. Future use of the Marsh Turbo Thrush on FS pilot and operational projects should be documented with particular attention given to spray atomization, spray equipment, and spray deposition on the target.

ACKNOWLEDGEMENTS

We express our appreciation to Dale Anderson and the Boise Cascade Corporation for making lands available to conduct this project; to Regional Forester, R-4, for administrative and contractual support; and to Director, MEDC, for cooperation and for providing the able assistance of James Kautz for photographic documentation.

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APPENDIX

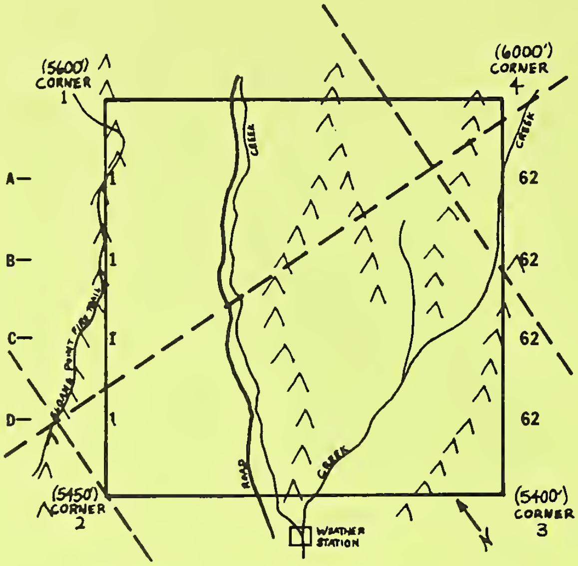
Six blocks were used, each 500 acres and measuring 4667 feet on a side (Fig. 6). These blocks were set up using surveyor chains, compasses, and clinometers with correction charts to compensate for slope. Survey crews first marked the actual block corners with flagging, and a tall tree nearest the block corner was marked with tree-top banners by using a line-throwing gun. While the map area (actual horizontal area) was 500 acres, actual surface area of the blocks was larger due to steep topography. During surveying the boundary corners usually came within 30 feet of the expected location.

Some of the relevant data pertaining to the individual blocks is shown in Table 16.

1. Sloan's block (Fig. 26). This block was located on two small streams that converged at the lower edge of the plot. The northwest side of the plot lay along a ridge line. The block then dropped into one stream valley, climbed up a small ridge (300 feet), dropped into another stream valley, and then climbed up the fall hillside to the southeast boundary. Vertical elevation difference within the block was around 800 feet. The block was flown with the first swath being laid along the northwest side and progressing toward the southeast. The first few swaths were relatively level, but most swaths required a climb or descent of several hundred feet; toward the end of the block the aircraft was required to climb almost 600 feet when going from the southwest corner to the northeast corner. South and southeast facing slopes of the block were fairly open with some ponderosa pine, and with some additional pine on the ridge top between the two streams. The rest of the block was predominantly Douglas-fir and grand fir 60-80 feet high. The north and northwest slopes contained very thick underbrush, making setting out the sampling lines very difficult.

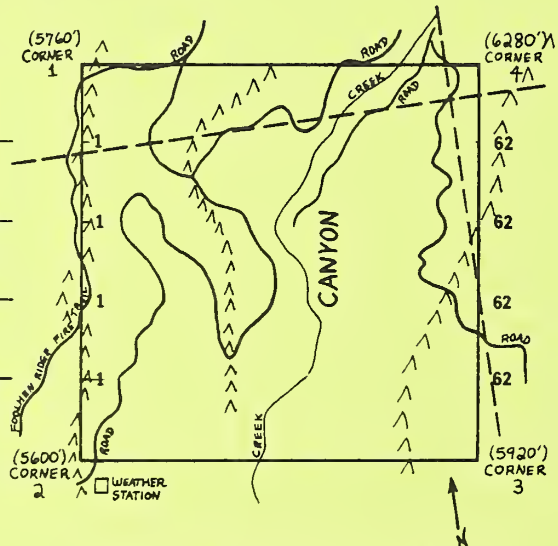
2. Hot Springs block (Fig. 27). This was a very rugged block straddling a small deep canyon and a high knoll on the north boundary. Aircraft started spraying parallel to the west boundary along a ridge line and moved eastward, dropped in and out of a small spur side canyon, then at about one-third of the way across flew up and down the deep canyon. This was made more difficult as the upper end of the canyon swung around a high sharp rocky knoll on the north boundary, necessitating that on some of the swaths the pilot fly up the canyon for about 2000 feet and pull up very sharply to climb out of the canyon and over the top of the knoll, a climb of almost 600 feet in less than 3000 feet. Similarly, many other swaths were partly along ridge tops, but then dropped into the canyon. Timber on this block was more open than on other blocks. Several of the very steep canyon sides (slopes of 60 percent or more) were quite bare with only a scattering of Douglas-fir; however, some of the more northerly exposures and valley bottoms contained dense stands of Douglas-fir and patches of lodgepole pine.

Figure 26. Sloan's Point spray block. T15N.,R4E Sections 13, 14, 23, 24. Gold Fork Quad., Valley County, Idaho. Turbo Thrush test, Idaho 1978.



SLOANS POINT PLOT NO. 1

Figure 27. Hot Springs spray block. T16N.,R4E Sections 24, 25; T15N.,R4E Sections 19, 30. Gold Fork Quad., Valley County, Idaho. Turbo Thrush test, Idaho 1978.



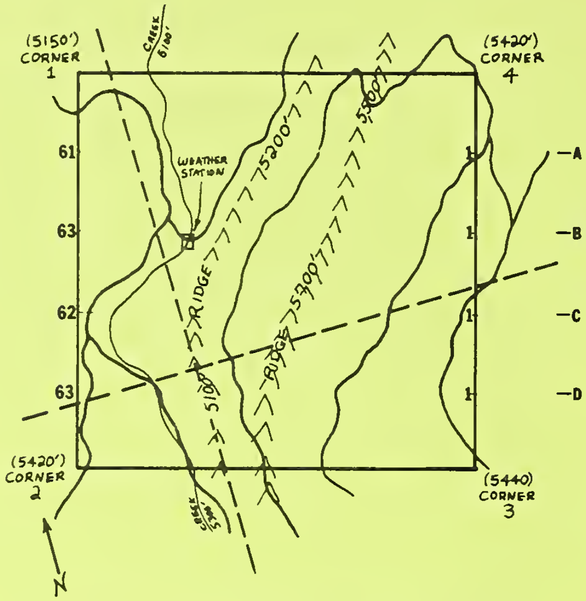
HOT SPRINGS PLOT NO.2

3. <u>French Creek block</u> (Fig. 28). The east boundary of this block bordered French Creek, about one mile south of its junction with Gold Fork River. This was the levelest block, with a vertical elevation difference of 600 feet. The block straddled a small unnamed creek and encompassed one small hill. Flight lines were flown in a north-south direction starting on the west side where the boundary paralleled a ridge line. Moving east, the flight lines dropped into the valley of the small creek, climbed up over a ridge containing the highest point in the plot, then dropped down the east boundary which paralleled French Creek. Slopes were generally gentle, usually less than 20 percent slope. Flight lines generally paralleled the prevailing ridges so the aircraft did not have to climb more than 200-300 feet between the north and south boundaries. The block was fairly heavily timbered with about two-thirds grand and Douglas-fir and one-third lodgepole pine. Some of the ridge tops and east slope had old growth of ponderosa pine 70-100 feet high (less than 10 percent of block area). Some patches of brush grew along the small stream.

4. <u>Eagle Nest block</u> (Fig. 29). This block was located on the side of Eagle Nest Mountain with the eastern boundary within a few hundred feet, elevation-wise, of the mountain top. This was the highest block, with the eastern boundary nearly 7000 feet MSL. It had a generally western exposure and was located on a steep mountainside with numerous cliffs, large rock outcroppings, and deep draws. The predominant feature of the plot was a very high rocky ridge that ran east-west almost through the center of the block; rock outcroppings on this ridge ranged from 200 to 400 feet higher than the surrounding slopes. Elevation difference within the block from the lower (southeast) corner to the highest point (northeast corner) was approximately 100 feet. The block was sprayed in a north-south direction starting on the lower edge of the plot and working upward. Since swaths were parallel with the mountainside it required flying over sharp rocky ridges. This necessitated steep climbs and rapid descents in the middle of most swaths. Stand composition was more variable than in the other five blocks. The block contained several clear cuts (total area 17 percent), large expanses of open rocky slopes or exposed rock surface (11 percent), open park-like stands of old growth ponderosa pine of 100 feet-plus (20 percent), mixed stands of lodgepole pine (20 percent), with the remaining area mixed Douglas-fir and grand fir (32 percent).

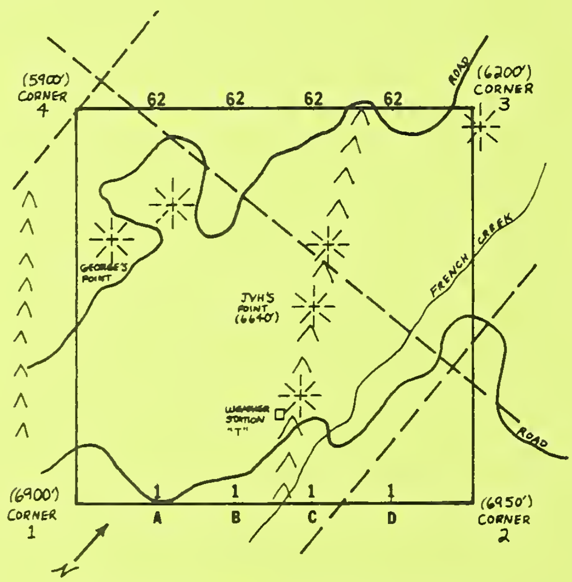
5. <u>Saddle block</u> (Fig. 30). Located near the pass leading out of the south end of Little Valley, this was the southern-most of the six blocks. It was laid out north-south with the eastern edge paralleling the creek at the valley bottom, and the west boundary paralleling the ridge on the west side of the valley. The south boundary had little elevation change but the north boundary was a 1000-foot climb from the creek bottom to the ridge top. Slopes ranged from 20-46 percent, with some slopes exceeding 50 percent for short distances. The block was sprayed in a north-south direction with the first swath laid along the east boundary. The first few swaths

Figure 28. French Creek spray block. T15N.,R4E Sections 2, 3, 10, 11. Gold Fork Quad., Valley County, Idaho. Turbo Thrush test, Idaho 1978.



FRENCH CREEK PLOT NO.3

Figure 29. Eagle Nest spray block. T15N.,R4E Sections 22, 23, 26, 27. Gold Fork Quad., Valley County, Idaho. Turbo Thrush test, Idaho 1978.

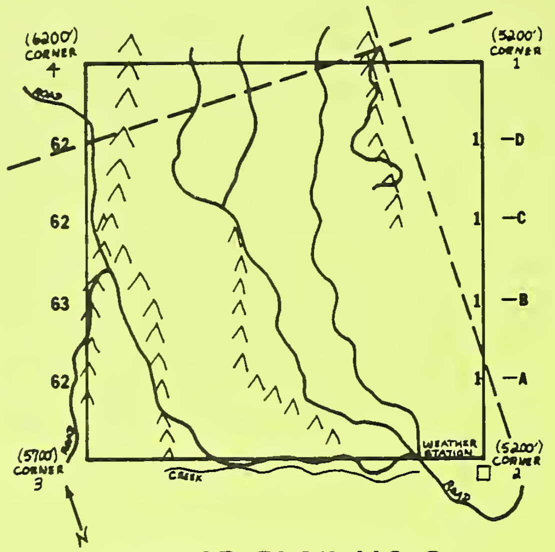


EAGLE NEST PLOT NO.4

changed little in elevation but as the plane worked westward up the mountainside it soon had to climb while going from south to north. At the maximum, however, the average elevation difference within an individual swath was only 500 feet. Timber at the bottom of the slope was predominantly a dense stand of lodgepole pine consisting of 6-8" diameter trees. Further up the slope it changed to grand fir and Douglas-fir with a scattering of older, taller ponderosa pine. Since the block was flown parallel to the ridge line and contained no major spur ridges or valleys, it was in general a fairly easy block to treat.

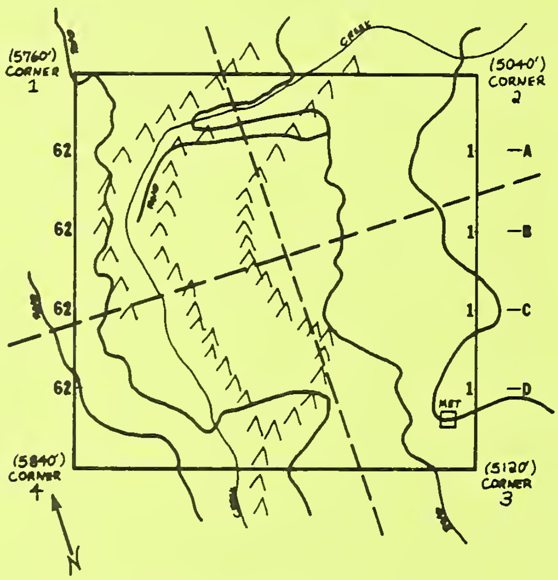
6. John's block (Fig. 31). East facing and located just to the north of Saddle block, the east boundary of ths block paralleled the bottom of the mountainside, and the west boundary paralleled the top of the ridge. A small side stream flowed into the block on the west side, swung north paralleling the edge of the block through a small valley, then swung east to parallel the north edge before exiting through the northeast corner. The block was flown in a north-south direction starting along the east boundary and working uphill. In general, it required mostly flying parallel to the slope except on the north edge where the plane was required to dip in and out of a small valley. During most swaths the aircraft did not have to change elevation by more than 200 feet even when dipping into the small valley. Therefore, while the total elevation difference in the block was almost 800 feet from east to west, the plane flying north-south had a fairly straight and level flight path paralleling the mountainside.

Figure 30. Saddle spray block. T15N.,R4E Sections 17, 20, 21. Gold Fork Quad., Valley County, Idaho. Turbo Thrush test, Idaho 1978.



SADDLE PLOT NO. 5

Figure 31. John's spray block. T15N.,R4E Sections 8, 9, 16, 17. Gold Fork Quad., Valley County, Idaho. Turbo Thrush test, Idaho 1978.



JOHN'S PLOT NO.6

Table 16. Summary of block information. Turbo Thrush test, Idaho 1978.

Block no.	Block name	Elevation (ft.) Lowest	Highest	Ownership	Location
1	Sloan's Point	5100	6000	BC	T.15N.,R4E Section 13, 14, 23, 24
2	Hot Springs	5480	6280	BC	T.16N.,R4E Section 24, 25 T.15N.,R5E Section 19, 30
3	French Creek	5100	5700	BC	T.15N.,R4E Section 2, 3, 10, 11
4	Eagle Nest	5900	6950	BNF	T.15N.,R4E Section 22, 23, 26, 27
				BC	T.15N.,R4E Section 22, 28
5	Saddle	5200	6200	BC	T.15N.,R4E Section 17, ,20, 21
6	John's	5040	5840	BC	T.15N.,R4E Section 8, 9, 17
				ID	T.15N.,R4E Section 16

1 Data from U.S. Geological Survey topographic maps

2 BC=Boise Cascade Corp.; BNF=Boise National Forest; ID=State of Idaho

3 All plots located in Valley County, west central Idaho.

DISCLAIMER STATEMENTS